Power development in professional rugby players.

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Ph.D.

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2011

Declaration

I hereby declare that this thesis has been composed by myself, that the work is the result of my own investigations except where assistance has been otherwise acknowledged, that the work has not been previously submitted in candidature for any other degree, that all sources of information have been specifically acknowledged by means of references, and that consent is provided for the thesis to be made available for photocopying and for inter-library loans.

Some of the results obtained from this thesis have been published as follows:

Kilduff, L.P., Bevan, H. R, N. Owen, M.I.C. Kingsley, N. Owen, M. Bennett, P. Bunce, D. Cunningham. Optimal Loading for Peak Power Output during the Hang Power Clean in Professional Rugby Players. *International Journal of Sports Physiology and Performance*, 2: 260-269 2007.

Kilduff, L. P., Owen, N., Bevan, H. R., Bennett, M., Kingsley, M. I. C. & Cunningham. D. Influence of Recovery time on Postactivation Potentiation in Professional Rugby Players. *Journal of Sports Science*, 26: 795-802. 2008.

Bevan, H. R., Owen, N., Cunningham, D., Kingsley, M. I. C. & Kilduff, L. P. Complex Training in Professional Rugby Players: Influence of Recovery Time on Upper Body Power Output. *Journal of Strength and Conditioning Research*, 23: 1780-1785, 2009.

Bevan, H. R., Bunce, P. J., Owen, N., Bennett, M., Cook, C., Cunningham, D., Newton, R., & Kilduff, L. P. Optimal Loading for the Development of Peak Power Output in Professional Rugby players. *Journal of Strength and Conditioning Research*, 24: 43 – 47, 2010.

Bevan, H. R., Cunningham, D. J., Tooley, E. P., Owen, N., Cook, C. & Kilduff, L. P. Influence of Postactivation Potentiation on Sprinting Performance in Professional Rugby Players. *Journal of Strength and Conditioning Research*, 0: 1 – 5, 2010.

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Acknowledgements

This dissertation would not have been possible without the guidance and the help of several individuals who in one way or another contributed and provided valuable assistance in the preparation and completion of this study.

I particular would like to thank Dr Liam Kilduff my supervisor for his support, direction and encouragement.

Dan Cunningham and Nick Owen whose contribution to this research was invaluable.

The England and Wales Cricket Board for their support over the last three years.

And finally Ann, William and Thomas for their support in whatever I do.

Summary

The ability to develop high levels of muscular power is considered an essential component of success in many sporting activities. Currently, a number of training methods exist aimed at developing muscular power such as training at the optimal load for Peak Power Output (PPO) and complex training, however to date there is no real consensus as to the most effective way of implementing these training modalities into elite sport.

The aim of the first experiment was to determine the optimal load for PPO during the Jump Squat, Bench Press Throws and Hang Power Clean in a group of professional rugby players. This was achieved by comparing the PPO at various loads of the subject's predetermined estimated 1 RM in a randomised and balanced order for Hang power cleans, (HPC) Bench Press Throws (BBT) and Jump Squats (JS). The results of this study indicate that relative intensity had a significant effect on PPO during the HPC, BBT and the JS and that peak values were obtained in our athletes when working against an external load that was equivalent to 80% 1RM in the HPC, 30% 1 RM in the BBT and with BM only in the JS.

The second experiment aimed to determine the required recovery time for maximal benefits between the heavy resistance training (HRT) and subsequent upper and lower body explosive

performance in a group of professional rugby players. Twenty professional rugby players performed a countermovement jump (CMJ) at baseline and ~15 s, 4, 8, 12, 16, 20 and 24 min following a HRT bout (3 sets of 3 repetitions @ 87% 1RM of Squat). Power output (PO), jump height and peak rate of force development (PRFD) were determined for all countermovement jumps. Performance increased significantly following 8 min recovery between the HRT and the CMJ ($p < 0.001$) (e.g. jump height increased by 4.9 ± 3.0 %). The results of this experiment demonstrate that muscle performance during a CMJ can be significantly enhanced following bouts of HRT providing adequate recovery (~8 min) is given between the HRT and the explosive activity.

The aim of the final experiment was to determine the effect of PAP on sprint performance in professional rugby players. Sixteen professional male rugby players performed five, 10 m sprints (with 5 m split): baseline, 4, 8, 12 and 16 min after the preload stimulus (1 set of 3 repetitions of the back squat at 91% 1RM). No significant time effect over the duration of the study with regard to 5 m and 10 m sprint times. However, when individual responses to PAP were taking into account a significant improvement in sprint performance was observed over both 5 and 10 m compared to the baseline sprint. The results of this experiment indicate that sprinting performance is enhanced following a pre-load stimulus providing adequate and individualised recovery is given between the two activities. This may have important implications for training speed.

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Glossary of Terms

BM	Body Mass
BMS	Ballistic Measurement System
PPO	Peak Power Output
BP	Bench Press
BPT	Bench Press Throw
CMJ	Counter Movement Jump
RM	Repetition Maximum
JS	Jump Squat
Pmax	Maximum Power
HPC	Hang Power Clean
PO	Power Output
PAP	Post Activation Potentiation
IEMG	Integrated Electromyography
HRE	Heavy Resistance Exercise
HRT	Heavy Resistance Training
VGRF	Vertical Ground Reaction Force

CHAPTER ONE

GENERAL INTRODUCTION

The ability to develop high levels of muscular power is considered an essential component of success in many sporting activities. For example, Sleivert and Taingahue (2004) reported negative correlations between relative peak power output (PPO) during the split squat and 5 m sprint time (r=-0.65) and relative PPO during the traditional squat and 5-m sprint time (r=-0.66), which may indicate that increasing PPO will lead to an improvement in sprinting performance, a primary performance outcome in many team sports. Additional support for this concept comes from various studies in the sprinting literature that have shown improvements in lower body strength and power can lead to improvements in sprinting ability (Cronin & Hansen, 2005 and McBride et al., 2009).

Consequently, researchers have examined the effectiveness of various training methods proposed to enhance power. These training methods have included athletes trying to develop power while working against their body mass (e.g. plyometrics) (Jenson & Ebben, 2007 and Markovic, 2007) and also while working against external loads that equate to various intensities of their 1 RM (Newton *et al.*, 1997; Baker, Nance & Moore, 2001, Izquierdo, et al., 2002; Stone *et al.*, 2003 and Kawamori *et al.*, 2005) and methods that require athletes to work against a heavy load (>80% 1 RM) followed by a light load (e.g. Gosseen & Sale, 2000 and Baker, 2003) which has been described as contrast or complex training and relies on the physiological condition known as Postactivation Potentiation (PAP) (Baker, 2003)

One strategy that has been consistently identified as a possible method for developing neuromuscular power requires athletes to train at the optimal load that maximises PPO (Mayhew et al. 1992; McBride et al., 2002 and Harris et al., 2008) However, to date there is no uniform agreement between researchers at what intensity the optimal load for peak power occurs, with researchers suggesting that PPO can be produced when working against external loads that equate to 0% - 80% of 1RM (Kanenko et al., 1983; Wilson et al., 1993; Newton et al., 1997; Baker et al., 2001a; 2001b; McBride et al., 2002; Siegel et al., 2002; Stone et al., 2003; Sleivert et al., 2004; Kawamori et al., 2005 and Cormie et al., 2007). This inconsistency in the literature is apparent even when similar power activities have been studied. For example Baker et al., (2003) reported that for jump squats the optimal load occurred in the range between 55 – 59% of 1RM whereas Cormie et al. (2007) reported PPO to occur at 0%

The lack of consensus in the literature can be attributed to a number of factors, such as: the use of single versus multiple joint activities, (Kaneko et al., 1983 and Moss et al.,1997), the muscle or muscle group utilised (Baker et al., 2001a & 2001b and Izquierdo et al., 1999), exercise selection (Kawamori et al., 2005 and Cormie et al., 2007), the training experience and strength levels of subjects (Baker, 2001a) and methodological differences centred around whether peak or mean values are reported, what is included in the calculation and the equipment utilised to measure power output (Dugan et al., 2004).

Similar to the optimal loading literature, there has been an abundance of studies examining the effectiveness PAP on subsequent power output in both upper and lower body with conflicting results (Wilson et al., 1993; Gullich & Schmidtbleicher, 1996; Young et al., 1998; Baker, 2003 and Baker & Newton, 2005). For example, Baker (2003) examined the effectiveness of PAP on upper body power development and found that the power output was 4.5% greater in a bench throw activity performed 3 min after the preload (5 RM) compared to a bench throw performed without any preload. This finding has been verified by numerous researchers (e.g. Baker & Newton 2005, Young et al., 1998). However, some studies have reported no effect or even a slight decrease in power outputs followed the preload stimulus (Ebben et al., 2000; Gosseen & Sale 2000; Hrysomallis et al., 2001; Jensen & Ebben 2003; Jones & Lees, 2003; Brandenburg, 2005 and Hrysomallis et al., 2001). This conflict in the literature may in part be explained by some methodological differences in the various studies as highlighted by Hodgson et al. (2005) in his review (e.g. mode and intensity of the preload stimulus, type of explosive activity, training history of the subjects and rest interval within and between the preload stimulus and subsequent explosive activity).

The majority of the methodological limitations mentioned above can be overcome by careful experimental study design, however very little research has focused to the optimal recovery time between the preload stimulus and subsequent explosive activity. To date, there is no uniform agreement between the studies with recovery periods ranging from 0 to 18.5 min being reported in the literature (Young et al., 1998; Duthie et al., 2002; Baker, 2003; Chu et al., 2003; Gourgoulis et al., 2003 and Brandenburg, 2005) whilst to date only one study has directly examined the optimal recovery period between the preload and subsequent performance, Jensen and Ebben (2003). They examined recovery periods of 10 s, 1, 2, 3, and 4 min between the preload stimulus (squats) and the subsequent explosive activity (countermovement vertical jump) and concluded that there was no effect on jump performance following the preload stimulus at any of the specified recovery periods, however they suggested that greater than 4 min of recovery may be needed to see a performance enhancement.

Additionally, to date the majority of studies have examined the role PAP plays in improving performance during squat jumps and ballistic bench throws (Duthie et al., 2002; Baker et al., 2003 and Jensen & Ebben, 2003), research still needs to be carried out to see if PAP can be harnessed to enhance performance in more functional activities such as sprinting.

Therefore, in light of the above the aims of the present series of studies were: 1) to determine the optimal load for PPO during the Jump Squat, Ballistic Bench Throw and Hang Power Clean, 2) due to the conflicting research in terms of appropriate recovery periods between the HRT and the subsequent explosive exercise, to determine the optimal recovery time for maximal benefits between the HRT and the explosive activity, 3) due to the lack of research regarding PAP and its effect on activities directly transferable to sport, the aim of the present study was to investigate the effects of a pre-load stimulus on 5 and 10m sprint times of professional rugby players.

CHAPTER TWO

REVIEW OF LITERATURE

Optimal Load for Peak Power Output

To date, a great deal of research with regards to the development of neuromuscular power has focused on the optimum external loading that allows the musculoskeletal system to maximize peak power output (PPO). Based on the early findings from research studies there seemed to be two primary schools of thought with regard to the importance of the two variables that are used to generate peak power, namely force and velocity.

The proponents of the use of higher loads (i.e. force focused) suggested that lifting higher loads at a maximal rate was a superior method of power development due to its ability to recruit the highest threshold motor units (Tidow, 1990; Poprawski, 1983 and Verkhoshansky & Lazarev, 1989). Conversely, advocates of the use of lighter loads centre their theory that the greatest adaptations to resistance training occur at or near the training velocity (i.e. velocity focused) (Counsilman, 1976; Behm, 1988 and Kaneko et al., 1983). They have suggested that whilst force production is improved by training at near maximal loads, movement speed is compromised by the increased force and therefore does little to enhance power development compared to lighter loads.

More recently, researchers have started to revisit this issue and have tried to identify the optimal load for the development of peak power output (PPO). There is considerable support for the effectiveness of training at the optimal load for PPO and its effectiveness at improving performance (Mayhew et al., 1992; McBride et al., 2002 and Harris et al., 2008) For example, a recent study by McBride et al. (2002) compared the effect of athletes training with heavy (80% of 1RM) Vs. the optimal load for PPO during the Jump Squats (30% of 1RM) over an 8-week training period. They reported that athletes training at the 30% load improved both peak power, peak velocity and jump height in Jump squats with 30, 55 and 80% of 1RM, significantly increased their 1RM (145.8 ±9.8 to 157.8 ±10.2 kg) and tended to improve their times for the agility T-Test, 5, 10 and 20m sprint times compared with the athletes training at the 80% 1RM.

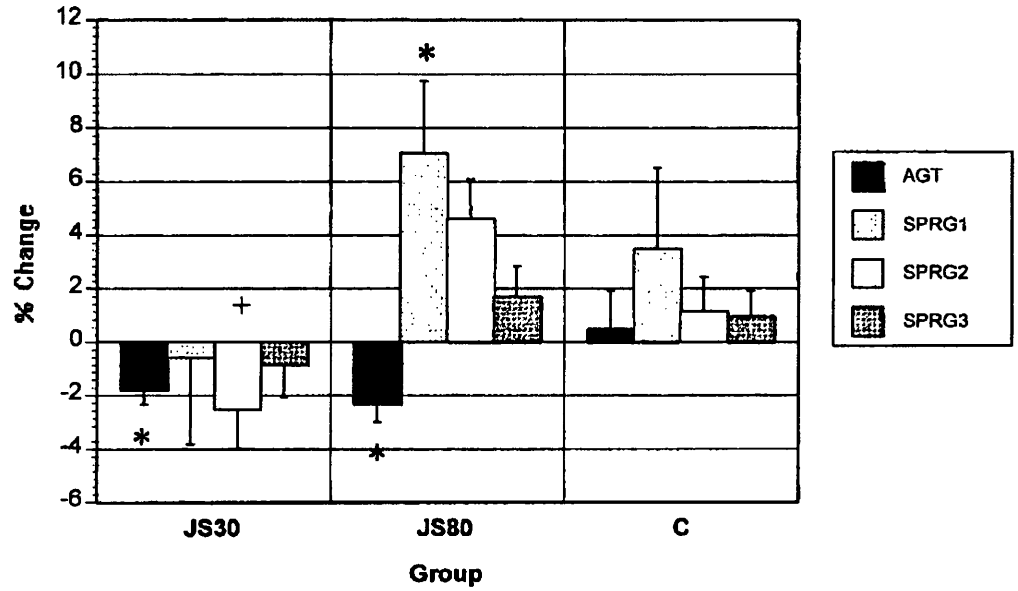

Figure 2.1 Percentage change from before training (Pre) to after training (Post) in the time to complete the agility test (AGT) and the time to reach gate 1 (SPRG1) (5 m), gate 2 (SPRG2) (10 m), and gate 3 (SPRG3) (20 m). * □ significant difference from Pre to Post for that group. + significant difference between the JS30 group and the JS80 group (*p* □ 0.05). (Taken from McBride et al., 2002)

Earlier work by Wilson et al. (1993) also suggested that training at 30% 1RM was more effective than training with body weight (unloaded depth jumps 0.2–0.8m) or traditional 'heavy' (6–10RM) squats for overall improvements in functional performance over the course of 10 weeks of training. Increases in countermovement jumps (17.6%) and jump- squats (15.2%) were significantly greater than the traditional (4.8% and 6.3%) and plyometric trained (10.3% and 6.5%) groups.

Improvements in PPO following training at the optimal load for PPO have also been accompanied with increases in dynamic performance (e.g., jumping and sprinting) (McBride et al., 2002 and Stone et al., 2003), with this evidence being used to reinforce the concept that training at the optimal load for PPO is an effective method for improving the muscle's ability to generate power. Further support for this is provided by Kaneko et al. (1983) who reported that subjects who trained at a load of 30% of maximal isometric force in an elbow flexor exercise for 12 weeks increased their PPO by 26%, which was significantly greater than the subjects who trained at 0, 60, or 100% of maximal isometric force.

Despite the above mentioned studies, who all have stated that 30% 1RM is the optimal load for PPO there is no uniform agreement between researchers at what percentage of 1 repetition maximum (RM) the optimal load for peak power production occurs, with researchers suggesting that PPO can be produced when working against external loads that equate to 0–80% of 1RM (Kanenko et al., 1983; Wilson et al., 1993; Newton et al., 1997; Baker et al., 2001a; 2001b; Siegel et al., 2002; McBride et al., 2002; Stone et al., 2003; Sleivert et al. 2004; Kawamori et al., 2005 and Cormie et al., 2007)

Table 2.1 Optimal Load Studies – Lower Body

Study	Subjects	Exercise Mode and Range of Loads	Mean or PPO	% 1RM or Load at which Max PO Occurred
Argus et al. (2011)	18 M Elite rugby union players	JS using loads of -28 to 60%1RM	Peak	0% in all but 2 subjects
Baker et al. (2001b)	32 professional and semi-professional rugby league players	JS across loads of 40, 60, 80 and 100kg – system mass	Mean	55–59% 1RM
Bourque & Sleivert (2003)	16 males (eight power [six volleyball, two badminton], eight endurance athletes)	Parallel concentric JS across loads of 0, 30, 40, 50, 60, 70% 1RM Body mass included	Peak	Mean: 14% 1RM power athletes 0% 1RM endurance athletes
Cormie et al. (2007)	12 Division 1 Male athletes (Football players, Sprinters, long jumpers	Loads of 0, 12, 27, 42, 56, 71kg and 85% of each subject's 1RM in the JS and S	Peak & Relative	0% 1RM JS 56% 1RM S
Dayne et al. (2011)	11 M High school athletes	JS Loads of 0,(body Mass) 20, 40, 60, and 80% of squat 1RM	Peak	0%
Esliger & Sleivert (2003)	21 (11 M and 10 F) volleyball and basketball players	Parallel concentric JS across loads of 30, 40, 50, 60, 70 and 80% 1RM	Peak	63% 1RM
Harris et al. (2007)	18 Well trained rugby athletes	Concentric power output in machine JS 10 – 100% of 1RM	Peak & Mean	PPO 21.6 ± 7.1% 1RM Mean PO 39.0 ±8.6%1RM
Izquierdo et al. (1999)	26 middle-aged M (mean age 42y) and 21 elderly M (mean age 65y)	Concentric only and stretch-shorten cycle half- squats across loads of 0, 30, 45, 60 and 70% 1RM	Mean	60–70% 1RM for both age groups
Izquierdo et al. (2002)	70 M subjects – weightlifters, middle-distance runners, handball players, cyclists and controls	Parallel concentric JS across loads of 0, 30, Concentric only half-squats across loads of 30, 40, 50, 60, 70, 80, 90 and 100% 1RM	Mean	45 – 60% 1RM
Siegel et al. (2002)	25 M college-aged students	Squats across loads of 30, 40, 50, 60, 70, 80 and 90% 1RM	Peak	50–70% 1RM
Sleivert & Taingahue (2002)	30 M rugby, rugby league and basketball players	Split Jump Squats, Jump Squats across loads of 30, 40, 50, 60 and 70% 1RM	Mean	SS: 30–60% 1RM JS: 30–60% 1RM
Stone et al. (2003)	22 subjects with a range of training experience (7wk to >15+y)	JS and CMJ across loads of 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100% 1RM	Peak	Weakest subjects: 10% 1RM Strongest subjects: 40% 1RM
Thomas et al. (1996)	18 untrained females	Double leg-press	Peak	56–78% 1RM
Thomas et al. (2003)	19 M & 14 F NCAA Division 1 Soccer Players	SJ, BPT Hang Pull at 30, 40, 50, 60, and 70% of individual 1RM		SJ 30 – 40%1RM M 30- 50% 1RMF BPT 30% 1RM M 30-50% 1RM F
Turner et al. (2011)	11 M Professional rugby union players	Loaded JS at loads from 20 – 100% of 1-RM JS.	Peak	20% 1RM (Lightest load)
Weiss et al. (2002)	31 M fitness-trained lifters	Concentric-only parallel squats across loads of 30, 60 and 90% 1RM	Mean	30% 1RM
Weiss et al. (2002)	31 M fitness-trained lifters	Concentric only Squats (Parallel)	Mean	60% 1RM

Table 2.2 Optimal Load Studies – Upper Body

Study	Subjects	Exercise Mode and Range of Loads	Mean or PPO	% 1RM or Load at which Max PO Occurred
Baker et al. (2001a)	31 professional and semi-professional rugby league players	Concentric-only BP throw across loads 40, 50, 60, 70 and 80kg	Mean	55% 1RM
Baker 2001a	22 M professional rugby league players (NRL) 27 M college-aged players (SRL)	Concentric-only BP throw across loads 40, 50, 60, 70 and 80kg	Mean	NRL: 70kg (51% 1RM) SRL: 60kg (55% 1RM)
Bemben et al. (1991)	31 M college students	Rebound BP across loads of 30, 40, 50, 60, 70 and 80% 1RM	Peak	50% 1RM
Cronin et al. (2001)	27M Club Rugby players	Concentric and rebound BP and concentric and rebound BP throws across loads of 30, 40, 50, 60, 70 and 80% 1RM	Peak	50 – 70% 1RM
Jandacka & Uchytil (2011)	15 M Professional soccer players	Acceleration phase during a BP at 0, 10, 30, 50, 70, and 90% of their 1RM	Mean	30 -50% 1RM during acceleration phase
Izquierdo et al. (1999)	26 middle-aged M (mean age 42y) and 21 elderly M (mean age 65y)	Concentric only and stretch-shorten cycle BP across loads of 0, 30, 45, 60 and 70% 1RM	Mean	30 - 45% 1RM for both age groups
Izquierdo et al. (2002)	70 M weightlifters, middle-distance runners, handball players, cyclists and controls	Concentric only BP across loads of 30, 40, 50, 60, 70, 80, 90 and 100% 1RM	Mean	30 – 45%1RM
Mayhew et al. (1992)	21 M college students	Rebound BP across loads of 30–80% 1RM	Peak	40% 1RM pre-intervention 50% 1RM after subjects increased strength
Moss et al. (1997)	31 Well trained P.E. Students	Elbow flexion	Peak	35 and 50% of 1 RM
Newton et al. (1993)	45 M with at least 6mo bench-press training experience	Rebound BP throws across loads of 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100% 1RM	Mean	30 - 40% 1RM
Newton et al. (1997)	17 M exercise science students with 6mo weight training experience	Concentric only and rebound BP throws across loads of 15, 30, 45, 60, 75 and 90% 1RM	Mean	30 - 45% 1RM
Siegel et al et al. (2002)	25 M college students	BP across loads of 30, 40, 50, 60, 70, 80 and 90% 1RM	Peak	40 - 60% 1RM

Table 2.3 Optimal Load Studies – Full Body

Study	Subjects	Exercise Mode and Range of Loads	Mean or PPO	% 1RM or Load at which Max PO Occurred
Kawamori et al. (2005)	15 males included 8 National Collegiate Athletic Association Division II football players, 3 weightlifters, a rugby player, a bobsledder, a basketball player, and a recreationally trained man.	Hang power cleans (HPC) on a force plate at loads of 30, 40, 50, 60, 70, 80, and 90% 1RM	Peak & Mean	70%1RM for both Peak and Average
Cormie et al. (2007)	12 Division 1 Male athletes (Football players, Sprinters, long jumpers	10% intervals from 30 to 90% of each subject's 1RM in the PC	Peak & Relative	80% PC
Thomas et al. (2003)	19 M & 14 F NCAA Division 1 Soccer Players	Hang Pull at 30, 40, 50, 60, and 70% of individual 1RM		30 – 60% 1RM M & F

The relatively wide intervals of these ranges observed both within and between various tasks could primarily originate from the differences in the use of single versus multiple joint activities, (Kaneko et al., 1983 and Moss et al., 1997), the muscle or muscle group utilised (Baker et al., 2001a; 2001b and Izquierdo et al., 1999), exercise selection (Kawamori et al., 2005 and Cormie et al., 2007), the training experience and strength levels of subjects (Baker 2001b and Pazin et al., 2011) and methodological differences centred around whether peak or mean values are reported, what is included in the calculation and the equipment utilised to measure power output. (Dugan et al., 2004).

Training Experience and Strength Levels

Some of the inconsistency in the literature with regard to the optimal load for PPO might be related to the subjects training experience and their strength levels. Some support for this comes from Baker (2001b) who reported that the strong athletes in his study attained their PPO with significantly lower resistances in the range of 46–51% 1RM compared with the less strong who tended to utilise resistances of 58–69% 1RM. However this findings conflicts with that of Stone et al. (2003) who reported stronger athletes produced maximal power at higher percentage of maximum load (40% of 1RM) in jump squat than weaker subjects (10% of 1RM). There may be several reasons for the discrepancies in the findings between the two studies. Firstly, the sample size is relatively small with the 5 strongest and weakest subjects being compared in both studies. Furthermore, the conflicting findings highlight the difficulty of comparing two studies with methodological differences. For example Stone et al. (2003) identified the stronger athletes by performing a 1RM in a parallel squat and correcting it for body mass whilst Baker et al. (2001b) used a full squat (below parallel) and used absolute values. In addition Stone et al. (2003) insisted athletes went to parallel during the countermovement phase of the jump squat whilst Baker et al. (2001b) allowed a self selected depth. Finally, the subjects used by Baker et al. (2001b), in addition to being experienced in resistance training had recently undertaken a phase of power training, which may have caused specific adaptations that enabled them to produce their PPO at lower percentages of their 1RM.

Table 2.4: The differences in the resistance (percent 1RM) that evokes the Pmax in strong and less-strong athletes from different groups in 2 standard power exercises. (Taken from Baker 2001b)

Group	Subjects	Percent 1RM	1RM	Pmax
Bench press throws				
Study 1‡	Strong = 5	51.4 ± 3.9*	152.0 ± 8.4*	715 ± 37**
	Less strong = 5	57.9 ± 3.9	124.0 ± 6.5	645 ± 74
Study 2§	Strong = 6	46.9 ± 60*	153.3 ± 8.8*	652 ± 58*
	Less strong = 6	54.1 ± 2.9	120.0 ± 7.1	551 ± 50
Study 3§	Strong = 6	54.5 ± 5.6	131.7 ± 4.1*	606 ± 47*
	Less strong = 6	56.5 ± 4.0	91.7 ± 6.8	438 ± 46
Jump squats‖				
Study 1	Strong = 5	45.8 ± 6.4*	201.0 ± 8.9*	2,146 ± 162*
	Less strong = 5	69.0 ± 2.4	145.0 ± 5.0	1,696 ± 143
Study 2	Strong = 5	48.9 ± 10.8**	181.0 ± 17.8*	1,907 ± 240*
	Less strong = 5	63.7 ± 13.2	118.0 ± 13.0	1,604 ± 177
Study 3	Strong = 5	52.5 ± 8.2	178.0 ± 11.5*	1,831 ± 180*
	Less strong = 5	56.8 ± 11.9	142.0 ± 9.1	1,503 ± 161

† Pmax = maximal power; 1RM = 1 repetition maximum.
‡ Data reanalyzed from Baker et al. (7).
§ Data reanalyzed from Baker (4).
‖ Data from studies 1, 2, and 3 from Baker et al. (8).

Two studies undertaken by Baker et al. (2001a & 2001b) suggest that the type of resistance training undertaken prior to testing may be important. They reported that athletes specifically trained via both maximal strength and power training methods may generate their maximal power outputs at higher percentages of 1RM in both the Bench press throw and Jump squat, than athletes who have undertaken strength training only. Studies carried out by Mayhew et al. (1992) also reported shifts in optimal load for PPO in response to changes in strength with 12 weeks of weight training (10% increase in maximal strength) leading to the optimal load for PPO changing from 40% to 50% 1RM. This evidence would support the notion that both the training emphasis and the training status of the athlete within a yearly cycle are important considerations when attempting to identify the load that maximises power output. Although the precise mechanisms behind this are not currently known, Baker et al. (2001b) proposed that neural adaptations such as an increase in firing rates and motor unit recruitment might account for some of this change. Further support for this comes from a study by Hakkinen and Komi (1985) who reported that the change in performance during countermovement jump squats with a 40-kg barbell correlated strongly with the change in both concentric (r 0.95) and eccentric (r 0.87) Integrated electromyography (IEMG) after 24 weeks of power training. Baker et al. (2001b) suggested that this increase in IEMG may also be brought about through a reduction in inhibitory signals being feedback from the peripheral sensory receptors, such as the

Golgi tendon organs and power trained athletes may be better able to process and override the inhibitory signals that occur when lifting large resistances at high speeds. This may lead to an increase in the resistances that they require in order to produce their maximal power output and an increase in maximal power itself.

Exercise selection

Ballistic vs. Traditional

It has been suggested that Ballistic lifts, where the subject jumps with or releases the load, and Olympic style lifts are superior to traditional weight lifting activities for the development of power and the enhancement of athletic performance (Stone, 1993; Kawamori et al., 2005 and Cormie et al., 2007). Cormie et al. (2007) suggested that the difference in acceleration profiles of these lifts means that the optimal load for PPO would occur at different loads. They reported that PPO occurred at 0% of 1RM in the Jump Squat, 56% 1RM in the Squat and at 80% 1RM in the Power Clean.

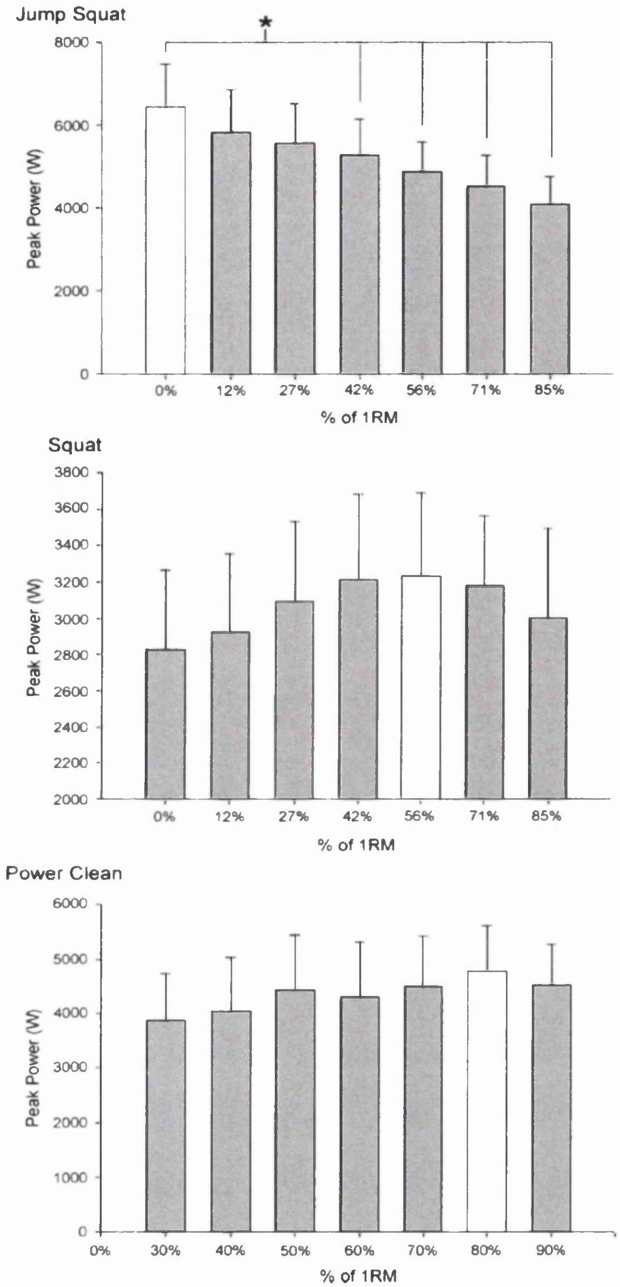

Figure 2.2 Absolute peak power output across the loading spectrum in the JS, S, and PC. * Significant (P e 0.05) difference between peak power at the optimal load (designated by open bar) and absolute peak power at other loads within the same lift. (Taken from Cormie et al., 2007)

They suggest that because the Jump Squat is ballistic in nature and the deceleration phase is much smaller than in a traditional Squat, greater velocities can be achieved and therefore maximum mechanical power output occurs at a lighter load than in the Squat, which has a much greater reliance on force for maximal power production. Conversely, in the Olympic lifts and their derivatives, which are widely recognised as capable of producing some of the highest average power outputs of all resistance-training activities, (Stone et al., 1993 and Haff et al., 2001) the optimal load appears to occur at higher percentage of 1RM (>70%). It is suggested that this occurs as a result of their inherent high force, high velocity nature, a view that is supported by both Garhammer (1993) and Kawamori et al. (2005) who found the optimal load for the hang power clean to be 70% of 1 RM.

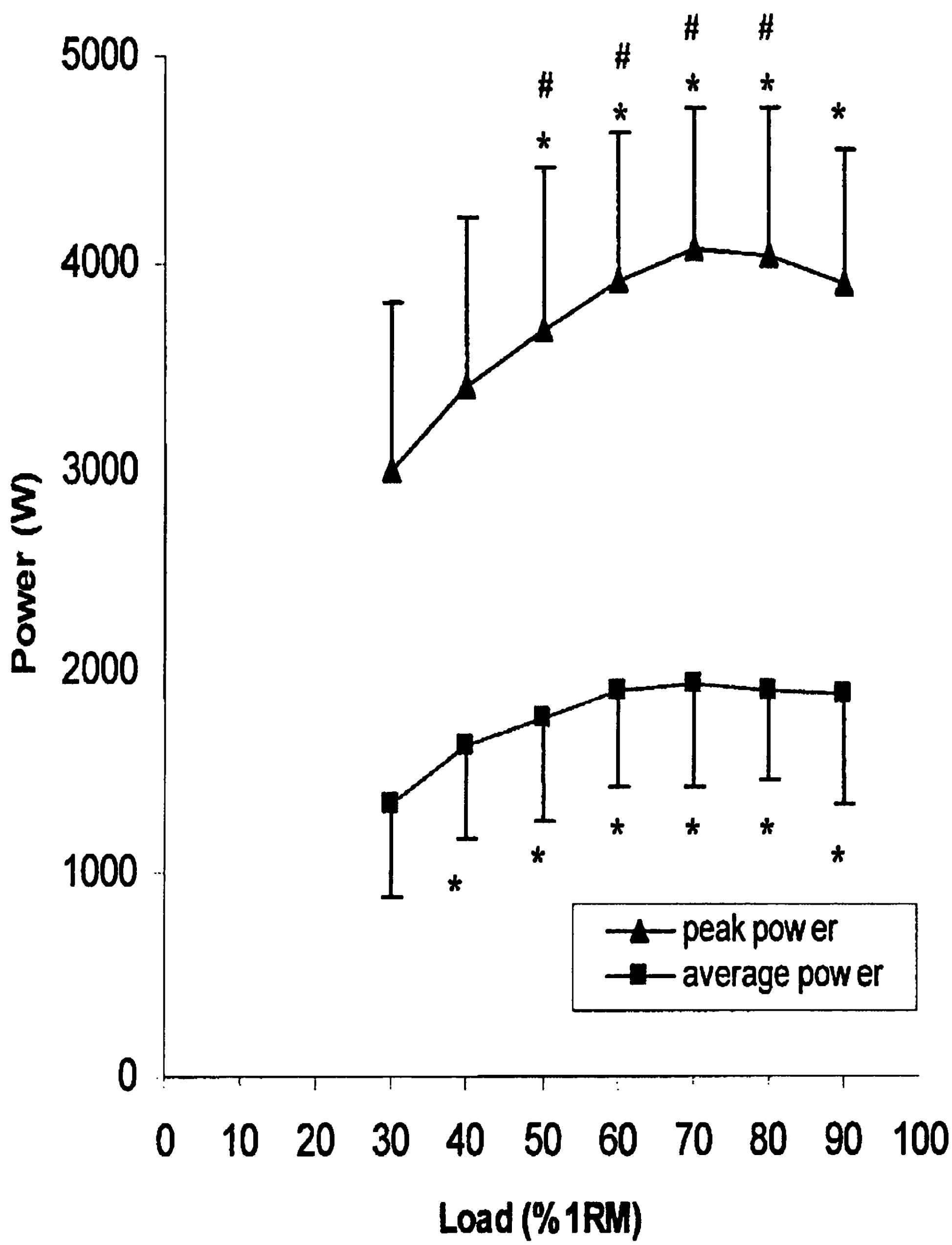

Figure 2.3 Peak and average power at loads of 30–90% of one repetition maximum (1RM) during the hang power clean. * significantly different from 30%; # significantly different from 40%. (Taken from Kawamori et al., 2005)

In the early studies that examined the effect of training at different loads, both Kanenko et al. (1993) & Moss et al. (1997) investigated power output during the elbow flexion. Kanenko et al. (1993) reported PPO to occur at 30% of 1RM and as a result it is widely reported as the load that maximises power output. However, as power was only measured at 0, 30 and 60% of 1RM, the load, which maximised power output, could have occurred anywhere between 30 – 60% of 1RM. Moss et al. (1997) had three groups of subjects train the elbow flexors of the non-dominant arm while the dominant arm served as a control. The groups trained at 90%, 35% or 15% of 1RM and power output was assessed pre and post training across a range of loads from 2.5kg to 90% 1RM with both the 90% and 35% loads being shown to be equally as effective at improving power output across a spectrum of loads.

Upper Body vs. Lower Body

The majority of upper body studies have focused on the optimal power in movement patterns associated with the bench press or bench press throw (Bemben et al., 1991; Mayhew et al., 1992; Newton et al., 1993; Izquierdo et al., 1999; Baker, 2001a; Baker et al., 2001a; Cronin et al., 2001 and Izquierdo et al. 2002) with the studies reported a range of loads between 30 – 70% 1RM. For example, Baker et al. (2001a) measured the power output of highly trained Rugby league players performing an explosive bench press type throw on a smith machine. The loads selected were 40, 50, 60, 70 and 80kg. They reported that the highest (mean) power outputs occurred at a resistance of 70.1± 7.9kg, which represented 55 ± 5.3% of mean1RM Bench Press for the group. However as there was no difference between the power output achieved with the 70 or 80kg loads and very little difference between the 60 and 80kg loads they suggested that the optimal load should actually be considered to occur between 50 – 60% of 1RM. Conversely, Newton et al. (1993) who investigated the effects of loads of 15, 30, 45, 60, 75, and 90% of 1RM on BT PPO reported that loads of 30 and 45% of 1RM BP produced the highest power outputs. They attributed the reduction in power that resulted with the use of with heavier loads, to the decrease in velocity that occurred, despite the proportional increase in force. It was suggested by Baker et al. (2001a) that methodological differences (e.g. reporting of mean vs. peak power) could partially explain the discrepancy between the findings of the two studies, however he also suggested that the highest power outputs occurred at a higher percentage of 1RM in his study as a result of the greater specific power training experience of the subjects he used.

To date, there is no uniform agreement as to the optimal load at which PPO is produced by the musculature of the lower body. Studies focusing on the lower body have measured power output in a variety of activities with the highest power output been reported to occur across a spectrum of load, for example Siegel et al. (2002) reported a optimal load of 70% 1RM but Cormie et al. (2007) reported an optimal load of 0% 1RM i.e. body weight. The suggestion that PPO occurs without any external load or at very low percentage of 1RM is an interesting one, and is supported by Bourque et al. (2003) who found that PPO in power athletes occurred at 14% whilst Stone et al. (2003) suggested it occurred at 10% of 1RM in weaker subjects, the lightest load that they examined. This is also true of the study conducted by Baker et al. (2001b) who reported that the highest (mean) power outputs occurred at a load of 40kg, but did not investigate any lighter loads, which may have produced even higher values.

Cronin & Slievert (2005) suggest that both the high peak power values and the fact that PPO occurs at relatively low percentages of 1RM in the studies by Baker et al. (2001b) and Bourqe et al. (2003) is as a result of the calculation method employed. They suggest that when variations of the Jump Squat (JS) are used as power activities, because body mass must be moved in addition to the external load it is appropriate to include the entire system mass in power calculations. i.e. including body weight as opposed to barbell only, and this is a key consideration in the range of loads reported as producing PPO.

Cormie et al. (2007) agree with this assertion and suggest that during a JS, the resulting force, velocity, and power should be determined by the athlete`s ability to accelerate the total system mass. (i.e., external load + body mass) Using this method the optimal load in the JS was identified by Cormie as 0% of 1RM which equated to (30%

of Maximal Dynamic Strength (MDS = 1RM + [body mass - shank mass]). Although not statistically different from all other intensities, the 0% of 1RM load was light enough for athletes to generate very high velocities (peak velocity: 3.66 ± 0.26 ms^{-1}), and the body mass provided enough resistance to produce a substantial force output (peak force: 1990.54 ± 338.55 N) and therefore elicited the greatest power output of the examined loads.

Duggan et al. (2004) illustrated the effect on the optimal load and the slope of the resulting load-power curve based on whether body weight is included in the calculations of power for two subjects. In Figure 2.4, it can be seen that the optimal load shifts from 20% of the subject A's 1RM to 50% of 1RM. Likewise, the optimal load shifts from 30 to 70% of 1RM for subject B. They concluded that body weight must be included in the calculation of power. This viewpoint is based on the fact that the inherent contraction properties of the leg extensors and the resulting force and velocity of the system are determined by the total load, body mass, and bar to be accelerated. The exclusion of body weight from power calculations causes substantial shifts toward the higher 1RM percentage for the optimal load. Also, if body mass, is excluded a proportionately larger error is inherent at lighter loads (e.g., 20–40%) compared to heavier loads (e.g., 70–80%). This error reverses the load-power relationship. In other words, when the body mass is excluded from light loads, a greater proportion of the load is now neglected, and the decreased load will result in a lower power value. On the other hand, at relatively high loads, the exclusion of body mass is a smaller relative reduction in the load; therefore, power at the higher loads is less affected by the exclusion of body weight in the calculations.

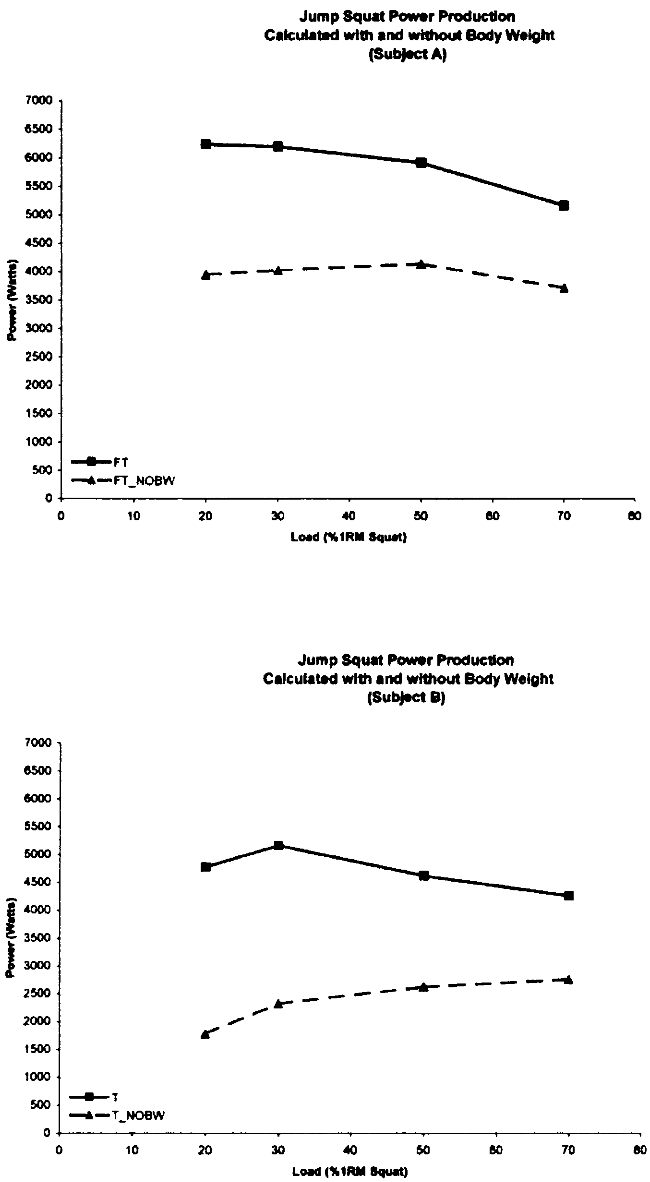

Figure 2.4. Representative power-load curves for jump squats when body weight of the subject is included or excluded for the same trials. FT = force platform and linear position transducer with body weight; FT_NOBW = force platform and linear position transducer without body weight; T = transducer only with body weight; T_NOBW = transducer only without body weight. (Taken from Duggan et al., 2004)

Methodological Differences

In addition to the reasons mentioned above it would appear that the experimental protocol, the reporting of average or peak power values and the equipment used for data collection could also play a significant role in the discrepancies reported in the literature for optimal loads and peak power outputs.

Data Collection equipment

Duggan et al. (2004) suggest that there are 4 commonly used experimental setups for the collection of data during the jump squat and the calculations of power and optimal load. The first method of calculating power utilizes only displacement data. The second method involves using only vertical ground reaction force (VGRF) data obtained from a force platform. The third method involves using a combination of VGRF and displacement data, the fourth method involves using an accelerometer system. Alemany et al. (2005) conducted a reliability assessment of ballistic jump squats and bench throws using the ballistic measurement system, equipment that collects displacement data only, and reported that performance variables collected on for the BT and JS were highly reliable over multiple sessions. Olsen et al. (2008) conversely recommend employing equipment that collects both displacement and force data to calculate power. Duggan et al. (2004) suggest that Data collection should involve both a force platform and a linear transducer when possible and argue that by using both measurement tools, fewer data manipulation is required, leading to more accurate results.

The Reporting of Average or Peak Power

The reporting of average or peak power values makes it difficult to compare the results from different studies. For example Baker et al. (2001a and 2001b) report mean power values while McBride et al. (2002) identify peak power values. Whilst technically it is correct to use either Dugan et al. (2004) propose that it would be better if it were standardised and if the goal is to report the parameter that is most associated with vertical jump performance, which Stone et al (2003) assert is associated with sprinting field events and other athletic performances, then peak power should be reported.

Post-activation Potentiation (PAP)

Post-activation potentiation (PAP) refers to the acute enhancement of muscular function as a direct result of its contractile history (Sale, 2004 and Hodgson, Docherty, & Robbins, 2005). *In vitro,* the potentiation of muscle twitch and increases in characteristics such as rate of force development (RFD) have been widely reported following the involuntary stimulation of muscle fibres (Requena, et al., 2005; Baudry & Duchateau, 2007a; 2007b and Requena et al., 2008). This has led to the hypothesis that PAP can be harnessed to augment performances *in vivo* where RFD is an important determinant (Gossen

& Sale, 2000; Sale, 2004 and Tillin & Bishop, 2009). PAP is commonly utilised through the medium of complex training where heavy resistance exercise (HRE) is performed prior to plyometric exercise with a view to augmenting performance in the plyometric activity. A popular example of such a complex pair is a back squat followed by a countermovement jump (CMJ)

Mechanisms of PAP

Whilst there is general consensus among the literature confirming the potential for contractile history to enhance subsequent contractions, specifically the potentiation of muscle twitch (Requena, et al., 2005; Baudry & Duchateau, 2007a; 2007b; and Requena et al., 2008), no such agreement exists in regards to the underlying mechanisms (Hodgson, Docherty, & Robbins, 2005). Research has generally considered two branches of explanation; physiological and neurological.

Physiological Mechanisms

Physiologically, PAP has primarily been attributed to the phosphorylation of myosin regulatory light chains (RLCs) (Sweeney, Bowman, & Stull, 1993 and Grange, Vandenboom, & Houston, 1993). RLC phosphorylation is catalysed by the enzyme myosin light chain kinase and dependent on the availability of calcium cations (Ca^{2+}). This enzyme is activated in response to the binding of Ca^{2+}, released from the sarcoplasmic reticulum during muscular contraction, to the protein calmodulin (Sweeney, Bowman, & Stull, 1993 and Szczesna, et al., 2002). It is suggested that RLC phosphorylation causes a change in the tertiary structure of the myosin protein, which is facilitative to a faster rate of cross bridge cycling and force production (Sweeney, Bowman, & Stull, 1993 and Grange, Vandenboom, & Houston, 1993). Szczesna et al. (2002) has further demonstrated that phosphorylation of RLCs renders the actin-myosin interaction more sensitive to Ca^{2+}. Together, this would imply that the effect of RLC phosphorylation would therefore be greater in conditions of low Ca^{2+} availability, as would be the case during twitch contraction (Abbate, et al., 2000). As Ca^{2+} availability is not a limiting factor during dynamic contraction, this may serve to explain some of the discrepancies shown between potentiation of muscle twitch *in vitro* and the carry over to *in vivo* studies (Grange, Vandenboom, & Houston, 1993 and Abbate et al., 2000).

Although it has received little attention in comparison to RLC phosphorylation, the angle of pennation within muscle may also be of potential importance to PAP. Given that force transmission to the tendon is reduced by a factor of $\cos\theta$ (where θ = pennation angle) (Fukunaga et al., 1997), a reduction in pennation angle is biomechanically advantageous to force production. Mahlfeld, Franke and Awiszus (2004) observed a reduction in pennation angle three to six minutes following three maximal voluntary contractions of the vastus lateralis (16.2° to 14.4°, $p < 0.05$). Whilst such a change may only contribute to around a 1% increase in force production, it is still possible that pennation angle may be an important contributing factor to PAP. It must be noted however, that dynamic pre-activation activities are likely to increase compliance of the muscle tendon unit (Bishop, 2003a), and may therefore offset any change in pennation angle (Tillin & Bishop, 2009).

Neurological Mechanisms

It is argued by some researchers that neural mechanisms predominate over physiological mechanisms. Studies have commonly used measurements of the Hoffman (H)-reflex to determine the magnitude of neural excitability (Hodgson, Docherty, & Robbins, 2005). If the amplitude of the H-reflex were increased it would be expected to result in the recruitment of higher threshold motor units given Henneman's size principle (Henneman, Somje, & Carpenter, 1965 and Wakeling, 2009). As the recruitment of these fast motor units is a key determinant of peak force production, and importantly the RFD, Gullich and Schmidtbleicher (1996) suggested that a pre-activation activity may enhance performance via an increase in the reflex contribution to neural drive and also demonstrated a strong relationship between the H-reflex and explosive isometric force development.

Potential limitations of H-reflex studies, such as Gullich and Schmidtbleicher's, were raised by Hodgson, Dochety and Zehr (2008), citing a lack of standardised posture during measurements, a lack of normalisation of the H-reflex and a lack of control of background electromyography. Hodgson, Dochety and Zehr (2008) demonstrated that PAP was independent of the H-reflex when these variables were accounted for, suggesting that this reveals the PAP effect to primarily reside on a physiological level, occurring within the muscle itself. Shima et al. (2006) also concluded that the enhancements observed as a consequence of PAP are associated with intrinsic muscular properties, not electrical changes. Further research is certainly necessary to determine an accepted mechanism/s for PAP. It is recommended that future research attempt to look at the potential for interaction of physiological and neural mechanisms, and whether the type of pre-activation activity modulates this interaction in any way.

In Vivo Studies

Whilst demonstrating that potentiation of muscle twitch can be achieved *in vitro*, it must be properly determined if appropriate pre-activation can be harnessed to elicit a beneficial performance effect. Given that enhancements observed in RFD of muscle fibres are more pronounced than increases in peak twitch force (Grange, Vandenboom, & Houston, 1993), it may therefore be hypothesised that PAP is most beneficial to high velocity movements. Speed and power performance, characterised by recruitment of maximal motor units in the shortest possible time, should therefore benefit from a pre-activation activity to a greater degree than low velocity strength performance. As a consequence, studies have commonly used short duration, explosive performance measures to gauge the effects of PAP.

Whilst large variation exists between authors' methodologies, there appears to be a general consensus that PAP can be attained given appropriate consideration of the relevant modulating factors. These modulating factors will be considered in detail later on in this review. Tables 2.5, 2.6 and 2.7 provide an overview of a number of studies investigating lower body, upper body and functional performance respectively and demonstrate the variation in the methodologies employed.

Lower Body Performance - Jumping

Jumping and sprinting tests are popular measures of lower body power performance given the high degree of transfer to sporting movements and their relative simplicity (McBride, Nimphius, & Erickson, 2005). Significant potentiation of jump performance has been reported in a range of studies (Young, Jenner and Griffiths, 1998; Chiu et al., 2003; French, Kraemer and Cooke, 2003; Gourgoulis et al., 2003; Burkett, Phillips and Ziuraitis, 2005; Gilbert & Lees, 2005; Clark, Bryant and Reaburn, 2006; Comyns et al., 2006; Rixon, Lamont and Bemben, 2007; Weber et al., 2008; Boullosa and

Tuimil, 2009 and Ruben et al., 2010) however several have results reported to the contrary (Jensen & Ebben, 2003; Scott & Docherty, 2004; Mangus, et al., 2006; Hanson, Leigh, & Mynark, 2007; Khamoui et al., 2009; Moir, Dale, & Dietrich, 2009 and Till & Cooke, 2009). Such discrepancies can partly be explained by the differences between methodologies employed to induce PAP.

Upper Body Performance

For the same reasons that jumps and sprints have been utilised to assess lower body performance, upper body studies have commonly utilised explosive pushing movements such as bench press throws (Baker, 2003), explosive push-ups (Hyrsomallis & Kidgell, 2001) and medicine ball throws (Markovic, Simek, & Bradic, 2008). Significant performance improvements have been reported by some (Baker, 2003; Markovic, Simek, & Bradic, 2008 and Matthews, O'Conchuir, & Comfort, 2009) but not others (Ebben, Jensen, & Blackard, 2000; Hyrsomallis & Kidgell, 2001 and Brandenburg, 2005).

Functional Performance

A number of authors (McBride, Nimphius, & Erickson, 2005; Chatzopoulos, et al., 2007; Rahimi, 2007; Yetter & Moir, 2008 and Linder, et al., 2010) have reported significant improvements in sprint performance following conditioning activities. Till & Cooke (2009) are the only authors unable to detect significant improvements in sprinting performance, although times were still improved by an average of 0.75%. The sprint trials utilised by Till & Cooke (2009) were over a distance of only 20 metres, which may potentially explain why statistical significance was not detected. Shorter sprints are subject to greater measurement error and therefore make improvements in performance harder to detect (Duthie, et al., 2006).

Table 2.5: Studies Investigating PAP - Lower Body Performance

Author	Performance Change	Performance Test	Rest Intervals	Preconditioning Contraction	Volume / Intensity (sets x reps)	Subjects
Behm *et al.* (2004)	↔	Isometric MVC knee extension	1min	Isometric MVC knee extension	1x10 secs	9 UT Males
	↔		5min		2x10 secs (1min RI)	
	***8.9% ↓ in T_r**		10min		3x10 secs (1min RI)	
	***7.5% ↓ in T_r**		15min			
Boullosa and Tuimil (2009)	***12.76% ↑ in height**	CMJ	2min	Montreal track	N/A	12 UT (End) Males
	***6.76% ↑ in height**		7min			
	***3.53% ↑ in height**		2min	T_{lim} @ max aerobic speed		
	↔		7min			
Burkett et al. (2005)	***3.27% ↑ in height**	CMJ	2min	Weighted box jumps	1 x 5 @ 10%BW (63.5cm)	29 RT Males
	0.87% ↑ in height			CMJ	1 x 5 @ 75% int.	
Chiu et al. (2003)	***Overall 1-3% ↑ in RT**	CMJ 30%1RM	5min	Back squat	1 x 5 @ 90%1RM (2min RI)	24; 7 RT, 17 UT
	***Overall 1-4% ↓ in UT**	CMJ 50%1RM	6min			(12 M, 12 F)
		CMJ 70%1RM	7min			
		SJ 30%1RM	5min			***RT > UT**
		SJ 50%1RM	6min			
		SJ 70%1RM	7min			
Clark, Bryant and Reaburn (2006)	Height > control	LCMJ (20kg)	4min	LCMJ	1 x 6 @ 40kg	9RT Males
	Height &***GRF** > control		7min			
	***Height & *GRF > control**		10min			
	Height > control		13min			
Comyns *et al.* (2006)	***↓ in FT and GRF at 30sec and 6min**	Single leg CMJs on sled	30secs	Back squat	1 x 5 @ 5RM	18 RT (9 Males, 9 Females)
	***↑ in best FT (1.3%)**		2mins			Males > Females NS
	***↑ in best GRF (3.3%)**		4mins			
			6mins			
French, Kraemer and Cooke (2003)	↔	CMJ	0-5 secs	Isometric MVC knee extens	3 x 3 secs (3min RI)	14 RT (10 Males, 4 Females)
	***5% ↑ in jump height**	DJ				
	↔	5 sec C-Sprint				
	***6.1% ↑ in T_r**	Isovelocity knee extension				
		CMJ				
	↔	DJ			3 x 5 secs (3min RI)	
	↔	5 sec C-Sprint				
	↔	Isovelocity knee extension				
	***3.0% ↓ in T_r**					

Table 2.5: (Cont) Studies Investigating PAP - Lower Body Performance

Author	**Performance Change**	**Performance Test**	**Rest Intervals**	**Preconditioning Contraction**	**Volume / Intensity (sets x reps)**	**Subjects**
Gilbert & Lees (2005)	~ 12.6% ↓ in RFD	Isometric knee extensions	2 mins	Back Squat	5 x 1 @ 1RM (5min RI)	15RT Males
	***~2% ↓in RFD**		10mins			
	***~8% ↑ in RFD**		15mins			
	***11.8% ↑ in RFD**		20mins			
	↔		60mins			
	~1% ↓ in jump height	CMJ	2mins			
	***~2.5% ↓ in jump height**		10mins			
	***~3% ↑ in jump height**		15mins			
	***~8% ↑ in jump height**		20mins			
	~1% ↑ in jump height		60mins			
	***6.7% ↑ in RFD**	Isometric knee extension	2mins	Back squat	5 x 1 @ P_p(5min RI)	
	~2% ↑ in RFD		10mins			
	~1.75% ↑ in RFD		15mins			
	~2% ↑ in RFD		20mins			
	~2% ↑ in RFD		60mins			
	***3.25% ↑ in jump height**	CMJ	2mins			
	~1% ↑ in jump height		10mins			
	~0.25 ↑ in jump height		15mins			
	↔		20mins			
	↔		60mins			
Gossen & Sale (2000)	↔	Dynamic knee extension	40secs	Isometric MVC knee extension	10secs	10 UT (6 Males, 4 Females)
	↔	Dynamic knee extension				
Gourgoulis *et al.* (2003)	***2.39% ↑**	CMJ	0-5secs	Back squat (half squat)	1 x 2 @ 20%, 40%, 60%, 80% and 90%1RM (5min RI)	11 RT Males, 9 UT Males
	(in RT = 4.01% ↑)					
	(in UT = 0.42% ↑)					
Hanson, Leigh & Mynark (2007)	↔	CMJ	5min	Back squat	1 x 4 @ 80%1RM	30 UT (24 Males, 6 Females)
Hilfiker *et al.* (2007)	1.1% ↑ in jump height	CMJ	1min	Drop jumps (hold landing)	1 x 5 from 60cm	13 RT Males
	***2.2% ↑ in P_{ave}**					
	1.8% ↑ in jump height	SJ	1min			
	1.5% ↑ in P_{ave}					
Jenson and Ebben (2003)	***4-13% ↓**	CMJ	10sec	Back squat	1 x 5 @ 5RM	21 RT (11 Males, 10 Females)
	↔		1min			
	↔		2min			
	↔		3min			
	↔		4min			
Khamoui *et al.* (2009)	↔	CMJ	5min	Back squat	1 x 2 @ 85%1RM	16 RT Males
					1 x 3 @ 85%1RM	
					1 x 4 @ 85%1RM	
					1 x 5 @ 85%1RM	
Mangus *et al.* (2006)	↔	CMJ	3min	Back squat (1/2 versus ¼)	1 x 1 @ 90%1RM	10 UT Males
Masamoto *et al.* (2007)	<1kg ↑ squat	1RM squat	30secs	Tuck jumps	1 x 3	12 UT Males
	***~5kg ↑ squat**			Drop jumps	1 x 3	

Table 2.5: (Cont) Studies Investigating PAP - Lower Body Performance

Author	Performance Change	Performance Test	Rest Intervals	Preconditioning Contraction	Volume / Intensity (sets x reps)	Subjects
Moir, Dale and Dietrich (2009)	↔ ↔ ↔ ↔ ↔	Bilateral hops	2mins 4mins 6mins 8mins 10mins	Back squat	1 x 2 @ 80%1RM	10 RT Males
Rixon, Lamont and Bemben (2007)	Male: 1.7% ↑ height Female: 1.5% ↓ height Male: ***2.9% ↑ height** Female: 1.2% ↑ height	CMJ CMJ	3min 3min	Back squat Isometric MVC back squat	1 x 3 @ 3RM 3x3secs (2min RI)	30 UT (15 Males, 15 Females)
Robbins and Docherty (2005)	↔	CMJ after each isometric	4min	Isometric MVC back squat	3x7secs (8min RI)	16 UT Males
Ruben et al. (2010)	***15.2% ↑ in P_{ave}** ***11.7% ↑ in F_{ave}** 9% ↑ V_{ave} ***↑ PAP with 1RM/BW**	Horizontal hurdle jumps	5min	Back squat	1 x 5 @ 30%1RM 1 x 3 @ 70%1RM 1 x 3 @ 90%1RM	12 RT Males
Scott and Docherty (2004)	↔ ↔	CMJ Horizontal jumps	5min	Back squat	1 x 5 @ 5RM	19 RT Males
Tahayori (2009)	Male: ***5.6% ↑ height** Female: 5.1% ↑ height	CMJ	2min	LCMJ	5 x 3 @ 15%BW (weight vest) (30sec RI)	18 UT (10 Males, 8 Females)
Weber *et al.* (2008)	***5.8% ↑ mean jump height** ***4.7% ↑ peak jump height** ***5.8% ↑ peak GRF**	SJ	3min	Back squat	1 x 5 @ 85%1RM	12 RT Males
Young, Jenner and Griffiths (1998)	***2.8% ↑ jump height**	LCMJ	4min	Back squat	1 x 5 @ 5RM	10 RT Males

Key: PAP = Postactivation Potentiation, ↑ = Increase,↓ = Reduction, ↔ = No Effect, * = Significant, ~ = Almost Equal To, kg = Kilograms, min = Minutes, m = Metres, Pp = Peak Power, Pave = Average Power, Tp = Peak Torque, RFD = Rate of Force Development, FT = Flight Time, GRF = Ground Reaction Force, FI = Fatigue Index, Fave = Average Force, Vave = Average Velocity, Tlim = Time Limit, BW = Body Weight, RM = Repetition Maximum, CMJ = Countermovement Jump, LCMJ = Loaded Countermovement Jump, SJ = Squat Jump, MVC = Maximal Voluntary Contraction, C-Sprint = Cycle Sprint, EMS = Electrical Muscle Stimulation, RI = Rest Interval, RT = Resistance Trained, UT = Not-Resistance Trained

Table 2.6: Studies Investigating PAP - Upper Body Performance

Author	Performance Change	Performance Test	Rest Intervals	Preconditioning Contraction	Volume / Intensity (sets x reps)	Subjects
Baker (2003)	***4.5% ↑ P_{ave}**	BPT	3min	Bench press	1 x 6 @ 65%1RM	8 RT Males (Control = 8RT Males)
Baker and Newton (2005)	**4.7% ↑ P_{ave}**	BPT	3min	Explosive bench pull	1 x 8 @ 50%1RM	24 RT Males
Brandenberg (2005)	↔ ↔ ↔	BPT	4min	Bench press	1x5 @100%5RM 1x5 @ 75%5RM 1x5 @ 50%5RM	9 RT Males
Ebben, Jensen and Blackard (2000)	↔ GRF	Medicine ball power drop	0-5 secs	Bench press	3-5RM	10 RT Males
Hyrsomallis and Kidgell (2001)	↑ RFD ↑ peak force	Explosive push ups	3min	Bench press	1 x 5 @ 5RM	12 RT Males
Markovic, Simek and Bradic (2008)	↔ **8.3% ↑ throwing speed**	0.5kg medicine ball throw 4kg medicine ball throw	3min	Bench press	2 x 3 @ 3RM	11 RT Males (Control = 12RT Males)
Matthews, O'Conchuir and Comfort (2009)	***3.99% ↓ FT** 1.96% ↓ FT	Timed basketball push pass	4min	Bench press Medicine ball push pass	1 x 5 @ 85%1RM 1 x 5 @ 2.3kg	12RT Males

<u>Key:</u> PAP = Postactivation Potentiation, ↑ = Increase,↓ = Reduction, ↔ = No Effect, * = Significant, ~ = Almost Equal To, kg = Kilograms, min = Minutes, P_p = Peak Power, P_{ave} = Average Power, RFD = Rate of Force Development, FT = Flight Time, GRF = Ground Reaction Force, F_{ave} = Average Force, RM = Repetition Maximum, BPT = Bench Press Throw, RI = Rest Interval, RT = Resistance Trained, UT = Not-Resistance Trained

Table 2.7: Studies Investigating PAP - Functional Performance

Author	Performance Change	Performance Test	Rest Intervals	Preconditioning Contraction	Volume / Intensity (sets x reps)	Subjects
Chatzopoulos *et al.* (2007)	↔	30m sprint	3min	Back squat	10x1 @ 90%1RM (3min RI)	15 UT Males
	***3% faster 0-10m**	30m sprint	5min			
	***2% faster 0-30m**					
Faigenbaum *et al.* (2006)	2.6% ↑ in jump height	CMJ	2mins	Dynamic warm up	Weight vest with 2%BW	18 RT Females
	↔	Long jump				
	↔	10 yard sprint		Dynamic warm up	Weight vest with 6%BW	
	↔	CMJ	2mins			
	3.4% ↓ in jump length	Long jump				
	↔	10 yard sprint				
French, Kraemer and Cooke (2003)	↔	CMJ	0-5 secs	Isometric MVC knee extens	3 x 3 secs (3min RI)	14 RT (10 Males, 4 Females)
	***5% ↑ in jump height**	DJ				
	↔	5 sec C-Sprint				
	***6.1% ↑ in T_p**	Isovelocity knee extension				
		CMJ				
	↔	DJ			3 x 5 secs (3min RI)	
	↔	5 sec C-Sprint				
	↔	Isovelocity knee extension				
	***3.0% ↓ in T_p**					
Jo *et al.* (2010)	***↑ best overall P_p (7.1%), improved FI (8.9%)**	30 sec Wingate test	5min	Back squat	1 x 5 @ 85%1RM	12 RT Males
	***Rest duration of best PAP correlated w/ 1RM (r= -0.77)**		10min			
			15min			
			20min			
Linder *et al.* (2010)	***1.2% faster**	100m sprint	9min	Back squat	1 x 4 @ 4RM	12 RT Females
McBride, Nimphius and Erickson (2005)	***0.87% faster**	40m sprint	4min	Back squat	1 x 3 @ 90%1RM	15 RT Males
	0.47% faster	40m sprint		LCMJ	1 x 3 @ 30%1RM	
Rahimi (2007)	1.1% faster	40m sprint	4min	Back squat	2 x 4 @ 60%1RM	12 RT Males
	1.7% faster				2 x 4 @ 70%1RM	
	***3% faster**				2 x 4 @ 85%1RM (2min RI)	
Thompsen *et al.* (2007)	↔	CMJ	2min	Dynamic warm up	Weight vest with 10%BW worn for last 4 exercises	16 RT Females
	***2.5% ↑ jump length**	Long jump				
Till and Cooke (2009)	~0.75% faster	20m sprint	4 - 6 min	Deadlift	1 x 5 @ 5RM	12 RT Males
	~1.3% ↑ jump height	CMJ	7 - 9 min			
	↔	20m sprint	4 - 6 min	Tuck jumps	1 x 5 maximal jumps	
	↔	CMJ	7 - 9 min		3x3secs per leg (15sec RI)	
	↔	20m sprint	4 - 6 min	Isometric MVC		
	↔	CMJ	7 - 9 min			

Table 2.7:(Cont) Studies Investigating PAP - Functional Performance

Author	Performance Change	Performance Test	Rest Intervals	Preconditioning Contraction	Volume / Intensity (sets x reps)	Subjects
Yetter and Moir (2008)	~0.5% ↑ 0-10m speed ***~1.5% ↑ 10-20m speed** ~1.25% ↑ 20-30m speed ***~2.25% ↑ 30-40m speed**	40m sprint	4min	Back squat	1 x 5 @ 30%1RM 1 x 4 @ 50%1RM 1 x 3 @ 70%1RM	10 RT Males
	~0.5% ↓ 0-10m speed ~1.25% ↑10-20m speed ~0.1% ↓ 20-30m speed ~0.5 ↓ 30-40m speed	40m sprint	4min	Front squat	1 x 5 @ 30%1RM 1 x 4 @ 50%1RM 1 x 3 @ 70%1RM	

Key: PAP = Postactivation Potentiation, ↑ = Increase,↓ = Reduction, ↔ = No Effect, * = Significant, ~ = Almost Equal To, kg = Kilograms, min = Minutes, m = Metres, BW = Body Weight, RM = Repetition Maximum, CMJ = Countermovement Jump, LCMJ = Loaded Countermovement Jump, DJ = Drop Jump, MVC = Maximal Voluntary Contraction, C-Sprint = Cycle Sprint, RI = Rest Interval, RT = Resistance Trained, UT = Not-Resistance Trained

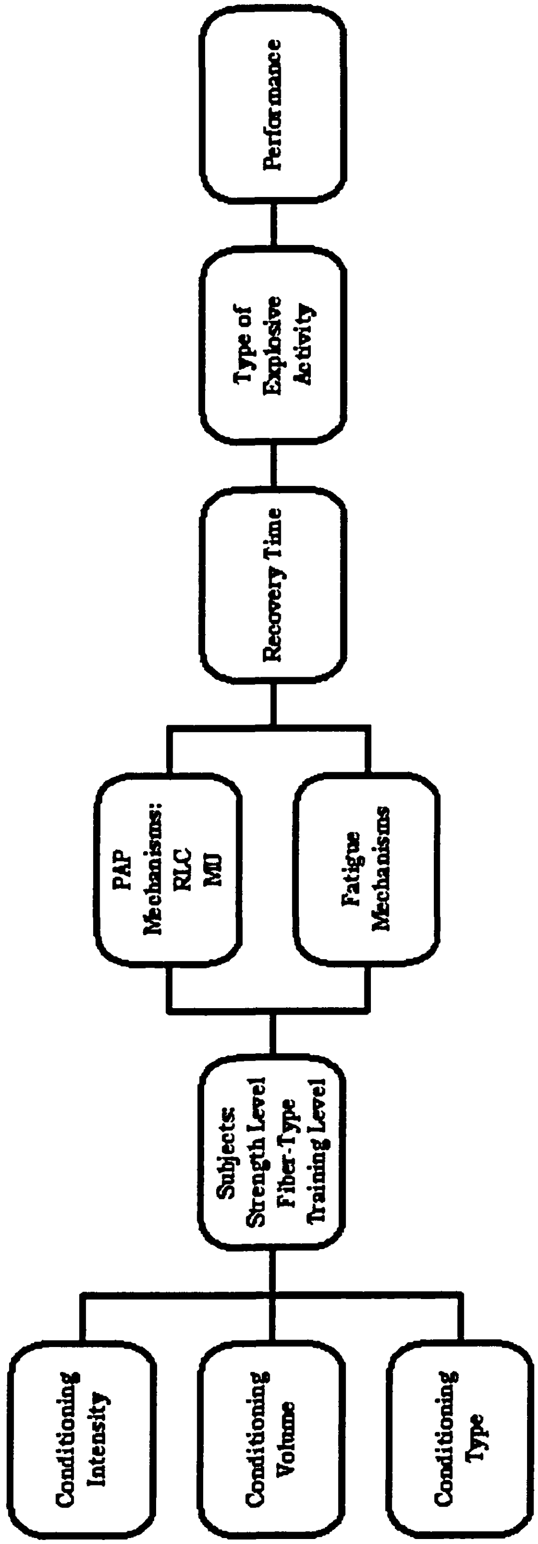

Figure 2.5: Factors Modulating PAP (adapted from Tillin & Bishop, 2008)

PAP Stimulus Mode

Lower Body Performance.

The majority of research has investigated the effects of high force movements through the use of heavy resistance exercise (HRE), as demonstrated in Table 2.2. Studies investigating performance in lower body tasks have almost exclusively utilised the back squat exercise. Till & Cooke (2009) are the only authors to have utilised the deadlift exercise and were unable to find a significant performance effect of doing so. This may however, be due to a variety of confounding factors and will be discussed in greater depth later on in this chapter.

Upper Body Performance.

With similar prolificacy to the back squat for the lower body, the bench press has been the preferred mode of HRE in upper body performance tasks (Table 2.3). Baker and Newton (2005) have however, demonstrated that performance of ballistic resistance exercise on the antagonist musculature, a bench pull, can also potentiate bench throw performance. Jaric et al. (1995) outlines a triphasic 'ABC' pattern of motor unit firing that is evident during ballistic muscle actions such as the bench throw which may explain the phenomenon. An initial *action* burst of activity is produced by the agonist, which is then followed by a *braking* burst exerted by the antagonist and finally a *clamping* burst from the agonist. Baker and

Newton (2005) propose that ballistic pre-activation of the antagonist musculature increases the efficiency of the *braking* effect exerted during the subsequent ballistic movement of the agonist, whereas 'traditional' pre-activation of the agonist musculature would be expected to enhance the initial *action* phase of activity. Maynard and Ebben (2003) and Robbins et al. (2010) have not reported such enhancements using non-ballistic pre-activation, suggesting that the specificity of the intervention may be of key importance. Further research would be required to truly evaluate the potential antagonistic interventions. Furthermore, whether or not agonist and antagonist PAP could be integrated together to further augment subsequent performance gains certainly poses an interesting question for future research to consider.

Isometric Contractions

Isometric contractions have been found to be a viable PAP inducing modality in the lower body by French, Kraemer and Cooke (2003) and Rixon, Lamont and Bemben (2007), however Gossen and Sale (2000), Behm et al. (2004), Robbins and Docherty (2005) and Till and Cooke (2009) have failed to report similar findings.

Rixon, Lamont and Bemben (2007) compared the PAP effect of dynamic (HRE) and isometric back squats, showing isometric squats to elicit greater potentiation. In male subjects a 2.9% increase in jump height was observed following the isometric protocol compared to a 1.7% increase following the dynamic protocol. The authors explained that by performing the movement at a fixed, stable point in the squatting movement, 125° of knee extension, the ability to maximise motor unit recruitment and firing frequency was therefore enhanced (Gullich & Schmidtbleicher, 1996 & Sale, 2004).

Till and Cooke (2009) were unable to replicate the findings of Rixon, Lamont and Bemben (2007). They found performance of a set of five heavy deadlifts to improve jumping and sprinting performance, although not to statistically significant levels, whereas three sets of three second isometric knee extensions were shown to have a slightly detrimental effect. Till and Cooke (2009) proposed that allowing only a 15 second recovery interval between isometric repetitions caused a fatiguing effect. Rixon, Lamont and Bemben (2007) and French, Kraemer and Cooke (2003) both observed PAP using a similar three second, three repetition protocol, however, both utilised inter-repetition recovery intervals of two and three minutes respectively. French, Kraemer and Cooke (2003) were unable able to demonstrate a PAP effect when contraction length was increased to five seconds.

It is possible that dynamic and isometric activities may have different mechanisms by which they are able to induce PAP. Isometric contractions activate a greater number of motor units (Duchateau & Hainaut, 1984) and consequently may result in greater RLC phosphorylation whilst the eccentric component of dynamic exercise may increase muscle spindle firing (Taylor, Butler, & Gandevia, 2000) and result in greater neural excitation. Differing mechanisms of fatigue are also demonstrated, with isometric contractions eliciting primarily central (neural) fatigue and dynamic contractions causing primarily peripheral (muscular) fatigue (Babault, et al., 2006). Whilst it is not known how these mechanisms interact, it appears that HRE requires a greater recovery period than isometric contractions (this will be discussed in subsequent sections). Comparisons of isometric and dynamic modalities at one fixed time point, as conducted by Rixon, Lamont and Bemben (2007), may therefore be inappropriate. The performance increases following HRE reported by authors such as Gilbert and Lees (2005) who have allowed for effective dissipation of fatigue, are greater than have been reported in any isometric studies (Table 2.2). It seems, therefore, that HRE can elicit a greater performance effect than isometric contractions given an appropriate recovery period.

PAP Stimulus Intensity

In vitro, PAP responses in type II muscle fibres have been shown to be significantly greater than in type I fibres (Vandervoort & McComas, 1983 and Hamada, et al., 2000 & 2003). This implies that the PAP stimulus activity should seek to recruit as many type II motor units as possible in order to maximise the potential beneficial effects of PAP. The order of motor unit recruitment in voluntary muscle contraction - the size principle (Henneman, Somje, & Carpenter, 1965; Wakeling, 2009) - would suggest that the motor units comprising type II muscle fibres are activated only in response to high force or high velocity contractions. The pre-activation activities should therefore consist of high force or high velocity movements if PAP is desired, regardless of the type of activity that is undertaken.

Looking at the utilisation of HRE, specifically the back squat, many authors have demonstrated PAP using loadings of 85%1RM and above (Chiu et al., 2003; Gourgoulis et al., 2003; Gilbert and Lees, 2005; McBride, Nimphius and Erickson, 2005; Comyns et al., 2006; Chatzopoulos et al., 2007; Rahimi, 2007; Rixon, Lamont and Bemben, 2007; Jo et al., 2010 and Ruben et al., 2010), however Jensen and Ebben (2003), Mangus et al. (2006) and Khamoui et al. (2009) have failed to. Factors such as insufficient recovery periods may account for PAP not being observed in certain studies and will be discussed in depth later. It may be postulated that Hanson, Leigh and Mynark (2007) did not demonstrate a PAP effect as consequence of using a loading of 80%1RM. Whilst Gilbert and Lees (2005), Rahimi (2007) and Yetter and Moir (2008) have reported PAP following the utilisation of loadings less than 85%1RM, Gilbert and Lees (2005) and Rahimi (2007) directly compared loading intensities of HRE and demonstrated that higher intensities elicit greater performance gains.

Similar loading intensities have been employed using the bench press in upper body investigations; some authors finding significant improvements using loadings in excess of 85%1RM (Markovic, Simek, & Bradic, 2008 and Matthews, O'Conchuir, & Comfort, 2009) where others have not (Ebben, Jensen, & Blackard, 2000; Hyrsomallis & Kidgell, 2001 and Brandenburg, 2005). Despite these findings, Baker (2003) has demonstrated PAP following a load of just 65%1RM.

Recovery

Whilst potentiation of muscle twitch is established to be greatest immediately following the pre-activation stimulus (Requena, et al., 2005; Baudry & Duchateau, 2007a; 2007b and Requena, et al., 2008), the same cannot be said for the performance benefit. The pre-activation activity will ultimately cause a certain level of fatigue in addition to any potential PAP effect, and whether or not the activity has a beneficial performance effect is governed by the interaction between these two responses.

Heavy Resistance Exercise

Gilbert and Lees (2005) have proposed that loading plays an important role in fatigue, comparing the interaction of two different squat loadings; a loading where peak power output (P_p) was achieved and a 1RM load. Performances following the P_p condition, a lighter load, were significantly improved two minutes at post-performance and decreased thereafter. In comparison, performances following the 1RM condition were shown to be decreased at two and ten minute post-performance and did not significantly improve over control values until fifteen minutes post-performance. This may suggest that PAP inducing modalities with lower loads and higher velocities will experience optimum PAP sooner than with HRE. Performance in the HRE condition peaked at twenty minutes post-performance, much later than has been reported in scientific literature, possibly as a result of using a greater loading (1RM).

Jensen and Ebben (2003), Scott and Docherty (2004), Mangus et al. (2006), and Khamoui et al. (2009), were all unable to show PAP after performing back squats using loads in excess of 85%1RM after utilising recovery periods of four, five, three and five minutes respectively. Given the findings of Gilbert and Lees (2005) it may be suggested that the recovery times in these studies were insufficient to determine whether their protocols were effective at eliciting PAP. Whilst authors such as McBride, Nimphius and Erickson (2005), Rahimi (2007) and Weber et al. (2008) have been able to show PAP following 3-4 minutes of recovery, it may be hypothesised that PAP had not yet peaked, and that greater performance increases could have been observed if the authors had evaluated performance at additional time points.

Isometric Contractions

The optimal recovery period for performance following isometric contractions is somewhat less clear. French, Kraemer and Cooke (2003) were able to show a 5% increase in depth jump height after just 5 seconds following the completion of 3 sets of 3 second contractions, although no improvement in a CMJ was detected. Gossen and Sale (2000) were unable to detect performance improvement 40 seconds following a single, 10 second isometric contraction, however, French, Kraemer and Cooke (2003) have established shorter (3 second) contractions to be superior to longer (5 second) contractions. Behm et al. (2004) found 10 second contractions to still not potentiate performance at 1, 5, 10 and 15 minutes post-contraction, with significant impairments observed at 10 and 15 minutes. Robbins and Docherty (2005) found no effect of 3 sets of 7 second contractions after a 4 minute recovery period.

Rixon, Lamont and Bemben (2007) reported a 2.9% increase in CMJ height 3 minutes following a similar 3 sets of 3 seconds protocol to French, Kraemer and Cooke (2003). The 3x3sec protocol was also used by Till and Cooke (2009), however, the authors were unable to detect a performance change between 4-9 minutes of recovery time. Whilst it is possible that 4 minutes recovery may be too long to elicit a performance effect, the inter-repetition recovery allowed by Till and Cooke (15 seconds) is substantially lower than that allowed by French, Kraemer and Cooke (3 minutes) and Rixon, Lamont and Bemben (2 minutes). It is clear however, that determining the optimal recovery period following isometric contractions requires further investigation. Moreover, due to the high forces generated and concomitant recruitment of high threshold motor units, it is likely to be similar to or possibly exceed HRE when matched for time under tension.

Additional Factors to be Considered

Strength Levels

Inter-subject differences have been proposed to play an important role in the modulation and effectiveness of PAP, subjects' strength levels appearing to be the most important of these characteristics. Chiu et al. (2003) reported athletically trained individuals to experience potentiation as a result of heavy back squats while performances of recreationally trained individuals were impaired. Chiu et al. (2003) cites greater muscle activation in the athletic trained population as allowing for greater H-reflex potentiation and/or RLC phosphorylation. In a similar vein Gourgoulis et al. (2003) demonstrated that athletes able to half squat in excess of 160kg exhibited a greater PAP response (4%) than athletes unable to (0.4%). Rixon, Lamont and Bemben (2007), although using a group of subjects with inferior strength levels to both Chiu et al. (2003) and Gourgoulis et al. (2003), were still also able to show a small effect of strength on PAP response, although not to significant levels.

Ruben et al. (2010) has since reported higher correlations ($r = 0.81$, $P = 0.001$) between percentage PAP and 1RM performance.
It may also be the case that stronger individuals have enhanced recovery mechanisms than weaker individuals and therefore require less recovery to be able to benefit from PAP. For example, Jo et al. (2010) demonstrated the recovery duration eliciting best performance in a Wingate cycle test to be significantly correlated with 1RM back squat ($r = -0.77$, $p < 0.05$).

The superiority of stronger athletes may also be explained through fibre type percentage. For example, given the role of type II muscle fibres in PAP response (Vandervoort & McComas, 1983; Hamada, Sale, MacDougall, 2000 & 2003), fibre type distribution is certainly an important consideration. Given also that a strong relationship between strength and percentage of type II fibres has been well established (Aagaard & Andersen, 1998), it may be speculated that stronger subjects are able elicit greater benefits from PAP due to a greater percentage of type II muscle fibres.

CHAPTER THREE

Experiment 1

Optimal Loading for the Development of Peak Power Output in Professional Rugby Union Players

INTRODUCTION

The ability to develop high levels of muscular power is considered an essential component of success in many sporting activities. Consequently, researchers have examined the effectiveness of various training methods proposed to enhance power. As previously mentioned, one training strategy consistently identified as a possible method for developing PPO requires athletes to train at the optimal load that maximises PPO (Harris et al, 2008; Mayhew et al., 1992 and McBride et al., 2002) however, to date there is no uniform agreement between researchers on the optimal load for peak power production with researchers suggesting that PPO can be produced when working against external loads that equate to 0% - 80% of 1RM (Baker et al., 2001a, 2001b; Cormie et al., 2007; Kaneko et al., 1983; Kawamori et al., 2005; McBride et al., 2002 and Wilson et al., 1993). This conflict in the literature with regard to the optimal load for PPO can, in part, be explained by numerous methodological differences in the various studies, such as the reporting of use of different types and mode of exercise, average versus peak power values, inclusion of barbell only or entire system mass in calculation (Dugan et al., 2004), strength levels of the subjects (Baker 2001b) and the reporting of average versus peak power values (e.g. Baker et al., 2001a; 2001b and McBride et al., 2002).

For example, Baker (2001b) reported that stronger athletes produced maximal power output at lower percentages of their 1RM compared to weaker athletes in both the BBT and JS, while Stone et al (2003) on the contrary reported stronger athletes to produce maximal power at higher percentage of maximum load (40% 1RM) in jump squat than weaker subjects (10% 1RM).

Another confounding factor that adds to the conflict in the literature, is the reporting of the optimal load of peak power versus mean power development. For example, in the study by Baker et al (2001b) they report that the optimal load for maximising power output is in the range of 47-63% of the subjects 1 RM for the lower body compared to the work by Cormie et al. (2007) who report 0% of 1 RM (body mass only) as the optimal. At first these results may seem very conflicting but in the study by Baker et al (2001b) they are reporting the optimal load for average power output compared to Cormie et al. (2007) who are reporting the optimal load for peak power output.

In addition to differences in data collection and analysis, methods comparisons between the various studies is problematic as a result of the differences in exercises performed with the majority of studies examining the optimal load for PPO during traditional upper (bench press or ballistic bench press) and lower (squats or jump squats) body resistance training exercises. However, it is well established that Olympic-style weightlifting movements (e.g. snatch, power clean and hang power clean) are known to produce power outputs that are far in excess of the power outputs obtained during the traditional squat and bench press type movements. For example, Stone et al. (1993) reported a power output of 3000 W during a barbell snatch compared to 1100 W during a traditional squat exercise in the same lifter and emphasis the important role Olympic lifts play in the development of power.

Therefore in light of the inconsistency that exists within the existing scientific literature, the aim of the present study was to determine the optimal load for PPO during the Jump Squat, ballistic bench throw and hang power clean in a group of professional rugby players.

METHODS

Experimental Approach to the Problem

During this within subject design study each subject was required to attend the laboratory on at least 3 occasions. The objective of the first testing session was to determine the subject's 3 RM for the hang power clean, squat, bench press and to allow the subjects to become familiarized with the study procedures that were to follow. During the experimental days, subjects were required to perform maximal effort Hang power cleans, (HPC), *Photograph 1 appendices page 179*, Bench Press Throws (BBT), *Photograph 2 appendices page 180,* and Jump Squats (JS), *Photograph 3 appendices page 181,* at various loads of their predetermined estimated 1 RM in a randomised and balanced order, with 3 attempts at each load in order to help identify the optimal load for peak power development.

Subjects

Forty-seven professional male rugby players (Table 3.1) who supplied written informed consent, volunteered to take part in the present study which was approved by the university ethics committee. Testing took place during the final week of pre-season training (end of August) and the players had just finished a phase of power development training. Players were recruited on the basis that they were engaged in a structured weight-training program for at least 2 years prior to the start of the study and were able to complete the HPC, BBT and JS with correct technique as assessed by a qualified strength and conditioning coach.

Table 3.1: Physical Characteristics of Subjects at baseline (n = 47)

Variables	**Mean ± SD**
Weight (kg)	101.3 ± 12.8
Stature (cm)	184 ± 8
Age (dec.yrs)	25.5 ± 4.8
1RM Bench Press (kg)*	124 ± 19
1RM Back Squat (kg)*	181 ± 24
1RM Hang Power Clean (kg)*H	107 ± 13

Values are Mean ± SD.
* Estimated from their 3RM Strength Testing

Experimental Procedures

Prior to the commencement of the main experimental trial, subjects visited the laboratory in order to become familiar with the testing methods and to have their 1 RM Hang Power Clean, Bench Press and Back Squat measured. During the familiarization trial, subjects practiced performing the HPC, JS, and BBT. Subjects reported to the laboratory on the morning of testing after having refrained from alcohol, caffeine and strenuous exercise the day before. Following the measurement of each subject's stature and body mass, subjects underwent a standardized warm-up which comprised 5 min light intensity cycling, followed by a series of dynamic stretches with an emphasis on stretching the musculature associated with the HPC, BBT and JS depending on the testing session.

On test day 1 subjects performed a maximal effort hang power clean on a portable force platform (Kistler portable force platform, model 9286AA) at loads of 30, 40, 50, 60, 70, 80 and 90% of the subject’s predetermined 1 RM in a randomised and balance order, with 3 attempts at each load. Only 12 players performed the HPC protocol due to injury or technical issues with the HPC.

On test day 2, following the standardized warm-up, subjects performed a maximal effort BBT on a Smith machine at loads of 20, 30, 40, 50, and 60 % of the subject’s predetermined 1 RM in a randomised and balanced order, with 3 attempts at each load. Lower body testing was carried out on the same day and in the same manner as upper body testing with the exception of weighted JS replaced the BBT as the mode of exercise and subjects completed an additional load of 0% 1RM (BM only) for the jump squats. Only 36 players performed the JS protocol due to injury or technical issues with the JS.

Consumption of water (500 mls) was permitted during each test. Room temperature was maintained between 20-24° C. Verbal encouragement was given to maximize performance.

Measurements

Strength Testing

Prior to the start of the strength testing session, all subjects underwent a standardized warm-up, which comprised light intensity cycling for 5 min, followed by a series of dynamic movements with an emphasis on warming up the musculature associated with the Hang Power Clean, Squat or Bench Press.

For HPC subjects then performed 3 warm-up sets of 3 repetitions at approximately 50, 60 and 70 % of their estimated 1 RM. Following this the subject's attempted 3 repetitions of a set load and if successful, the lifting weight was increased until the subject could not lift the weight through the full range of motion. The hang power clean technique was carried out as previously described (Kawamori et al., 2005; Ebel & Rizor, 2002 and Souza et al., 2002), briefly subjects were required to lower the barbell to the hang position (just above the knee) and then with triple extension of the knee, hip and ankle lift the barbell explosively in a vertical plane and catch the bar on the shoulders in a ¼ squat position. All subjects had been previously exposed to 3 RM testing for the hang power clean.

For Squat and Bench Press subjects performed 3 warm-up sets of 10 repetitions at 50 % of their estimated 1 RM. Following the warm-up sets, subjects attempted 3 repetitions of a set load and if successful, the load was increased until the subject could not lift the weight through the full range of motion. All subjects had been previously exposed to 3 RM testing for both the bench press and squat.

A 5 min rest was imposed between all attempts to allow subjects adequate time to replenish energy stores. The 3 RM was determined after 3-4 attempts in all subjects. Both the Bench Press and Squat movements were carried out as per the International Powerlifting Federation rules (2007).

Power Testing

On entering the laboratory for the optimal loading testing sessions subjects completed an identical warm-up as done on the strength testing day.

On testing day 1, following a 10 min recovery period, subjects performed a maximal effort hang power cleans on a portable force platform at loads of 30, 40, 50, 60, 70, 80 and 90% of the subject's predetermined estimated 1 RM in a randomised and balance order, with 3 attempts at each load. The hang power cleans were performed in the same manner as described in the strength testing section with subjects been instructed to lift the barbell as explosively as possible with correct technique.

Force Platform

A Kistler portable force platform with built-in charge amplifier (Type 9286AA, Kistler Instruments Ltd, Farnborough, UK) was used for data collection of the ground reaction force (GRF) time history during the hang power clean. Throughout the testing the GRF were sampled at 1000 Hz and the force platform's calibration was confirmed before and after testing.

On testing day 2 following a standardized warm up and a 10 min recovery period subjects performed maximal effort BBT at loads of 20, 30, 40, 50, and 60% of the subject's predetermined 1 RM in a randomized and balanced order, with 3 attempts at each load and a 5 min recovery period between each load. During each BBT, the subject was instructed and encouraged to lower the bar from the starting position and throw it as high as possible. To avoid the effects of deceleration and achieve maximal bar velocity, the bar was released at the top of the range of motion. During each throw, subjects were required to keep their head, shoulders, and trunk in contact with the bench as well as their feet in contact with the floor.

For the measurement of lower body PPO, subjects performed maximal effort JS at loads of BM only, plus 20, 30, 40, 50, and 60% of the subject's predetermined 1 RM in a randomised and balanced order, with 3 attempts at each load and a 5 min recovery period between each load. The JS were performed with the subjects squatting down to a predetermined depth and explosively jumping to the highest height attainable.

Ballistic Measurement System (BMS)

PPO from both the JS (summing body mass and barbell mass as the load in the calculation) and BBT was calculated using the software provided with the BMS (Fitness Technology, Adelaide, Australia). The BMS was used to collect bar displacement data during both the JS and BBT. The BMS comprises a cable-extension potentiometer (distance transducer) that produces a variable voltage output proportional to the extension of the 3 m cable. The data collection system (XPV6+, Fitness Technology, Adelaide, Australia) of the BMS and interfaced to the computer via USB then captured the displacement data at a sampling rate of 500 Hz. The BMS was calibrated against known distances for the range over which the JS and BBT were performed; this calibration was performed before all testing sessions. The reliability of the BMS has been assessed for the measurement of PPO during SJ (with additional weight) and BBT in a study by Alemany et al. (2005). In this study the authors reported intraclass correlation coefficients of 0.93 and 0.96 for peak power obtained during the BBT and JS, respectively.

Data Analysis for Hang Power Clean

The vertical component of the GRF of a subject performing a hang power clean was used in conjunction with the weight of the subject bar system (the combined effect of the subject and the weight of the bar) to calculate the instantaneous power, velocity and rate of force development (RFD) of the subject-bar's centre of gravity (Kawamori et al., 2005). Power was calculated using the standard relationship: Power (W) = vertical GRF (N) x vertical velocity of the centre of gravity of the subject-bar system. The velocity of the centre of gravity of the subject-bar system was calculated by numerically integrating the net vertical GRF (net vertical GRF = vertical GRF- weight of the subject-bar system). Numerical integration was performed using the trapezium rule for intervals equal to the sample width. The area of a strip, of width equal to the sample width, thus represented the impulse during that time interval. Using the relationship that impulse equals change in momentum; the strip area was then divided by the mass of the subject-bar system to produce a value for the change in velocity of the centre of gravity of this system. This change in velocity was then added to the centre of gravity's previous velocity, to produce a new velocity at time equal to that particular interval's end time.

Instantaneous rate of force development (RFD) was calculated from the first derivative of the vertical GRF. Prior to numerical differentiation the vertical GRF was filtered using a dual pass Butterworth filter (low pass, 15 Hz cut off). Filter settings were determined from a pilot study and based on Fourier analysis and inspection. Peak RFD (PRFD) was taken as the highest RFD in the concentric phase of the lift.

Test-retest reliabilities for peak power, peak ground reaction force, peak velocity and PRFD were intra-class correlation (ICC) = 0.96, ICC = 0.98, ICC = 0.98 and ICC = 0.95, respectively.

Statistical Analyses

Following a test for the normality of distribution, data was expressed as the mean ± S.D. Statistical analyses was carried out using a repeated measures one-way analyses of variance (ANOVA) to determine whether there was a significant difference between the relative intensities for peak power output (PPO). When significant F values were observed ($P \leq 0.05$), paired comparisons were used in conjunction with Holm's Bonferroni method for control of type I error to determine significant differences. The level of significance was set at

$p \leq 0.05$ in the present study and all statistics were performed using SPSS 13.1 (SPSS Inc., Chicago, IL).

RESULTS

Ballistic Bench Throw (BBT)

Maximum PPO during the BBT was observed at a relative intensity of 30% 1RM in our group of athletes (Table 3.2, Figure 3.1). Statistical analyses revealed relative intensity (% 1RM) had a significant effect on PPO during the BBT (Effect size eta^2: 0.297; $F=1398.1$, $p < 0.001$). Subsequent paired comparisons revealed a significant difference between the PPO obtained at 30% 1RM and the PPO at 20 and 60% 1RM (Table 3.2, Figure 3.1). There was no significant difference between the PPO at 30, 40 and 50% 1RM during the BBT (Table 3.2, Figure 3.1). In addition, the PPO at 20% and 60% were not significantly different from each other (775.6 ± 25.3W vs. 773.3 ± 24.3W, $p > 0.05$) but both were significantly lower compared to all other intensities (Table 3.2, Figure 3.1).

Jump Squat (JS)

Statistical analyses revealed a significant effect of relative intensity on PPO during the JS (Effect Size eta^2: 0.709; $F=3078.4$, $p < 0.001$). Maximum PPO was recorded during the JS preformed at 0% 1RM. In addition, the PPO generated by the athletes when performing the JS with 0% 1RM was significantly higher than all other intensities. Also there was a significant difference between the power outputs at all relative intensities when compared to each other (Table 3.2, Figure 3.2).

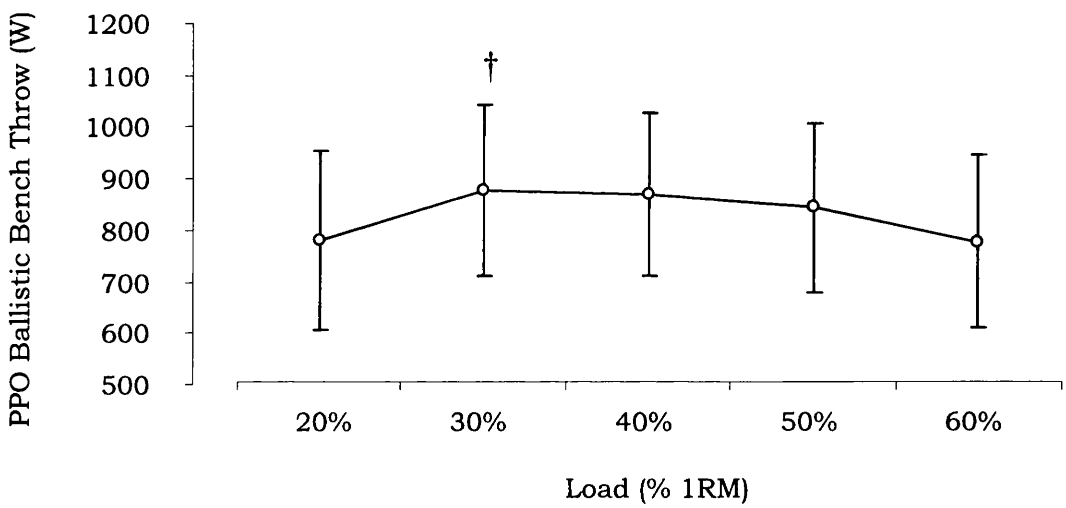

Figure 3.1 Peak power output at loads of 20 - 60% 1RM during the BBT.

Table 3.2: Peak Power Output during the Ballistic Bench Throw and Jump Squat with different relative intensities of 1RM.

	Peak Power Output (PPO) (W)	
Load (% 1RM)	**Ballistic Bench Throw (n=47)**	**Jump Squat (n=36)**
0%		4750.9 ± 529.4
20%	775.6 ± 25.3	4256.1 ± 489.0
30%	873.0 ± 24.2	4130.2 ± 462.6
40%	865.4 ± 23.1	3982.1 ± 371.5
50%	838.4 ± 23.7	3859.1 ± 390.7
60%	773.3 ± 24.3	3717.7 ± 406.4

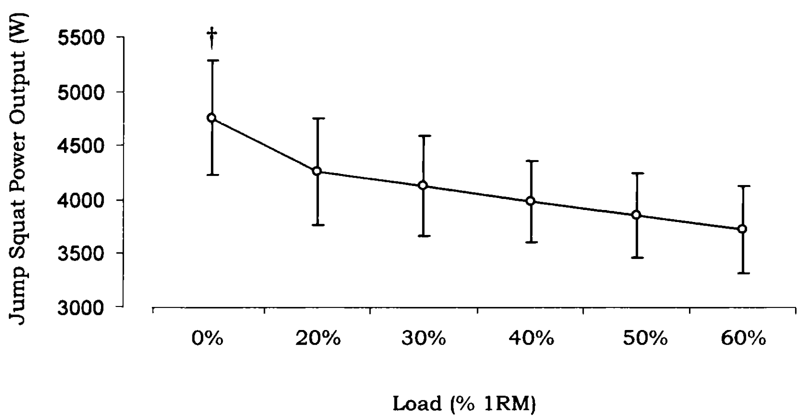

Figure 3.2 Peak Power output at loads of BM - 60% 1RM during the Jump Squat

Hang Power Clean

Power Output

Statistical analysis revealed that relative load (% 1 RM) had a significant effect on power output during the hang power clean (Effect Size eta^2 0.70; F=20.56, $p < 0.001$). Peak values for power output during the hang power clean were observed at a relative load of 80% 1 RM in our group of players (Table 3.3, Figure 3.3c). The power outputs generated during the hang power clean at the relative loads of 50, 60, 70 and 90% 1 RM were not significantly different when compared to the power output at 80% 1 RM (Table 3.3, Figure 3.3c).

Paired comparisons revealed no significant difference between 30 and 40% 1 RM in terms of power output during the hang power clean (3246 ± 553W vs. 3495 ± 669W, mean ± SD, p=0.346) however, the power outputs at these two relative loads were significantly lower compared to all other loads (Table 3.3, Figure 3.3c).

Velocity during Hang Power Clean

Peak velocity during the hang power clean was observed at the relative load of 50% 1 RM, with a peak velocity of 1.61 ± 0.21 $m \cdot s^{-1}$. Statistical analysis generated by the ANOVA revealed that relative load (% 1 RM) had no significant effect on velocity produced during the hang power clean (Effect Size eta^2 0.12; F=1.265, p= 0.29) (Table 3.3, Figure 3.3a).

Force Output and Rate of Force Development (RFD) during Hang Power Clean

The repeated measures 1-way ANOVA revealed a significant effect of relative load on GRF during the hang power clean (Effect Size eta^2 0.76; F=28.6, $p < 0.001$). Peak force was recorded at the highest relative load (90% 1 RM) during the hang power clean which was not significantly different to the force recorded during the hang power clean at 80% 1 RM (Table 3.3, Figure 3.3b). However, the force produced during the hang power clean at 80 and 90% 1 RM was significantly greater than the force produced at any of the other relative loads (Table 3.3, Figure 3.3d).

PRFD was also produced during the hang power clean at 90% 1 RM however again this was not significantly different when compared to the PRFD at any of the other relative loads (Effect Size eta^2 0.05; F=0.445, p =0.85) (Table 3.3, Figure 3.3d).

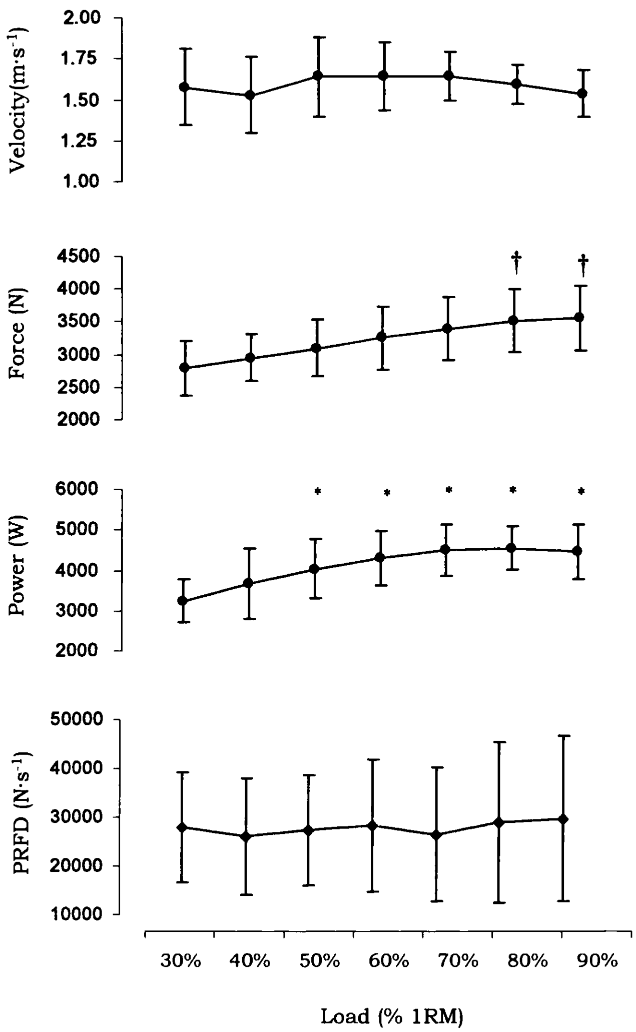

Figure 3.3: Velocity (A), Force (B), Power (C), PRFD (D) at loads 30-90% 1 RM during the hang power clean
†: Indicates significantly greater than 30-70% 1RM
*: Indicates significantly greater than 30-40% 1RM

Table 3.3: Performance characteristics during the hang power clean at various relative loads

	Performance Characteristics			
Load (%1RM)	Velocity ($m \cdot s^{-1}$)	Force (N)	RFD ($N \cdot s^{-1}$)	Power (W)
30%	1.58 ± 0.23	2799.6 ± 422.1	27999 ± 11237	3246.0 ± 552.8
40%	1.50 ± 0.23	2945.5 ± 372.5	27741 ± 11190	3494.7 ± 669.1
50%	1.61 ± 0.21†	3087.9 ± 469.3	28253 ± 10841	3902.0 ± 572.1
60%	1.60 ± 0.17	3274.5 ± 526.6	29802 ± 13043	4203.7 ± 588.4
70%	1.61 ± 0.13	3327.1 ± 502.8	25241 ± 12307	4346.9 ± 600.0
80%	1.59 ± 0.12	3487.0 ± 526.6	28948 ± 16340	4467.0 ± 477.2†
90%	1.51 ± 0.12	3544.2 ± 551.9†	29858 ± 17663†	4357.5 ± 623.0

†: Indicates where peak values were obtained

DISCUSSION

The primary findings of the present study was that PPO was maximized at a relative intensity of at 80% 1 RM during the hang power clean (HPC), 30% of 1 RM during the Ballistic Bench Throw (BBT) and 0% 1 RM in the Jump Squat (JS) in this group of professional rugby players. In order to maximise the power output during any exercise there must be a compromise between the two variables that contribute to power development, namely force and velocity. When the external resistance is too high then the velocity of movement will be low and hence PPO will not be optimised (Cormie et al., 2007). In the present study this compromise was achieved at a relative load of 30% 1 RM for the BBT, 0% 1RM for the JS and 80% 1 RM for the HPC.

Hang Power Clean

The finding of maximal PPO at 80% 1 RM in the HPC is slightly higher than that reported by Kawamori et al. (2005) (70% 1 RM). However, in the present study and the study by Kawamori et al. (2005) there was no significant difference between the power output at a range of loads (50-90% 1 RM) which may indicate large intra-individual responses to optimal loading for peak power output. It is therefore difficult to interpret whether these results are conflicting or not. If the interpretation is that these results are conflicting, then some researchers would suggest that the strength level of the athletes may have been a confounding factor. For example, Stone et al. (2003) reported that the load that maximized PPO was higher during the JS in a group of stronger subjects (40% 1 RM) compared to the group of weaker subjects (10% 1 RM), however not all researchers agree with this hypothesis (Baker et al., 2001b; Baker 2001b). In the present study the 1 RM for our group of subjects was 107 ± 13 kg compared to the 1 RM of 107 ±18.8 kg, which would suggest no real strength difference between the two subject groups. In addition, the different strength levels of the subjects within our study helps explain the findings that the power outputs at 50, 60, 70, 80 and 90% 1 RM were similar. Subjects in the present study had 1 RM hang power cleans of between 93-132 kg again showing large variants in strength levels and according to Stone et al. (2003) this would lead to subjects attaining their PPO at difference relative loads.

Further support of our findings comes from the study by Haff et al. (1997) who reported that peak power output was obtained at 80% 1 RM during the hang power clean, however in this study the authors only examined the power outputs against 3 external resistances (80, 90 and 100% 1 RM) and therefore it cannot be discounted that PPO might have been obtained at a relative load of less than 80% 1 RM.

Additionally, the HPC peak ground forces increased as a function of loads (Table 3.3) which is in agreement with previous studies (Newton et al., 1997 and Kawamori et al., 2005). In the study by Kawamori et al. (2005) and in the present study PRFD was unaffected by relative load which is in agreement with the findings of Schmidtbleicher (1992) who reported that

PRFD is equal for all loads that are higher than 25% of maximum force. Subjects in the present study produced a PRFD of 287 ± 147 $N \cdot s^{-1} \cdot kg^{-1}$ compared to 234.5 ± 95 $N \cdot s^{-1} \cdot kg^{-1}$ in the study by Kawamori et al. (2005), however direct comparison between both studies is very difficult in terms of PRFD due to various ways of calculating PRFD. To determine a peak value for RFD it is necessary to obtain an instantaneous value by taking the first derivative of force, with respect to time. Differentiation has a tendency to amplify any noise present in the raw signal, and therefore, filtering the original force time history is necessary to overcome this limitation. In the present study a butterworth low pass filter was used with a cut-off frequency of 15Hz (dual pass) with different filter settings altering the PRFD values, so direct comparison is not necessarily meaningful unless the same filter settings was used. The filter setting used in the study by Kawamori et al. (2005) was not stated in their methods section.

Ballistic Bench Throw (BBT)

The power output achieved at 30% 1RM in the BBT was significantly different to those achieved with 20% and 60% of 1 RM but not 40% and 50%, which may indicate that the intensity at which PPO is achieved in the BBT is a very individual response and may occur somewhere between 20% and 60% of 1 RM. This finding is supported by research by Mayhew et al. (1992) and Siegel et al. (2002) who reported that PPO was produced at a load that equalled 50% 1 RM and between 40-60% of 1 RM, respectively.

In a study by Kaneko et al. (1983) they reported that PPO occurred at 30% of 1 RM for the upper body which has resulted in this paper often being incorrectly cited as evidence that the load that maximises power output is 30% of 1 RM. Whilst it is true that PPO in that study was observed at intermediate movement velocities of approximately 30% of maximum shortening velocity and 30% of maximal isometric strength, only four loads, 0%, 30%, 60%, and 100% were utilised. Therefore the load that actually maximised peak power output could have occurred at any point between 30% and 60%.

Jump Squat

PPO was achieved with 0% 1 RM in the JS in this present study which was significantly higher than the power output at all other intensities. At first glance this may seem quite contradictory to previous findings (e.g. Siegel et al., 2002; Sleivert & Taingahue, 2004 and Stone et al., 2003). For example, in the studies by Siegel et al. (2002) and Sleivert & Taingahue (2004) they reported PPO was obtained when the subjects worked against external loads that equated to 50-70% of their 1 RM. However, more recent work by Cormie et al. (2007) and McBride et al. (2002) found that the optimal load for PPO in their group of athletes was 0% 1 RM (or body mass only) which is in direct agreement to the findings of the current study. Cormie et al. (2007) reported that this load elicited the greatest power output of all the examined loads (12%, 27%, 42%, 56%, 71%, 85%) and that the 0% of 1 RM load was light enough for athletes to generate very high velocities (peak velocity: 3.66 ± 0.26 $m \cdot s^{-1}$), and body mass provided sufficient resistance to produce a substantial force output (peak force: 1990 ± 338 N). Therefore this load permitted the most favourable combination of force and velocity to maximise power output.

Combined Comparison

In a review by Dugan et al. (2004) they suggested that the main discrepancies between the optimal load for PPO during the jump squat was the issue over the inclusion or exclusion of body mass into the calculation of power. In both the present study and the studies carried out by Cormie et al. (2007) and McBride et al. (2002) we included body mass into the calculation of lower body power for the main reason that according to Dugan et al (2004) the inherent contraction properties of the leg extensors and the resulting force and velocity of the system are determined by the total load, body mass, and bar to be accelerated and they demonstrated that the exclusion of body mass from the calculation of power causes a substantial shift towards the higher 1RM percentage for the optimal load.

Additionally, there are a number of other possible explanations for the discrepancies within the literature with regard to the optimal load for PPO such as the training status of the athlete. Baker (2001a) reported alterations in the optimal load for PPO in response to changes in strength and training emphasis within the yearly training cycle.

Cormie et al (2007) suggests that the difference in acceleration profiles of lifts could mean that the optimal load for power output will occur at different loads.. This principle is supported by the findings of the present study which demonstrates that higher relative loads are required to generate PPO during the hang power clean compared to the more traditional squat jumps (40-80% 1 RM) and ballistic bench press (40-70% 1 RM) and highlights the need for individual determination for the optimal load for peak power output for all major exercises used during training (e.g. hang power cleans, squat jumps, bench press) The potential factors contributing to these differences include the type of muscle action involved, strength level of subjects and single vs. multiple joint exercises (Kawamori et al., 2005). In addition, comparison of the peak power outputs produced by the subjects of this study in the hang power clean 4554 ± 551 W, 873 ± 24 W in the Bench Press Throw and 4291 ± 84 W during the and Jump Squat supports the work of Stone et al. (2003).

Findings from the current study can be used to individually determine the optimal training load for developing PPO. Although there is still much debate with regard to the correct method for developing power in athletes (e.g. plyometrics, training at the optimal load, complex training) there is support for the effectiveness of training at the optimal load for PPO and its effectiveness at improving performance. For example, in a study by McBride et al. (2002) they compared athletes training at 30% of their 1RM (suggested optimal load) or 80% of their 1RM over a 8 week training period and reported that athletes training at the 30% load tended to have greater increases in 20-m sprint times compared to the athletes training at the 80% load. This finding is also supported by the much earlier work of Wilson et al. (1993) who also found training at 30% load was more effective than plyometrics using body weight alone. Improvements in PPO have been accompanied with increases in dynamic performance (e.g. jumping and sprinting) (McBride et al., 2002; Stone et al., 2003) with this evidence being used to reinforce the concept that training at the optimal load for PPO is an effective method for improving the muscles ability to generate power. Further support of this is provided by Kaneko et al. (1983) reporting that subjects who trained at a load of 30% of maximal isometric force in an elbow flexor exercise for 12 weeks increased their PPO by 26% which was significantly greater than the subjects who trained at 0, 60 or 100% of maximal isometric force.

In conclusion, the results from the present study indicate that relative intensity had a significant effect on PPO during the HPC, BBT and the JS and that peak values were obtained in our athletes when working against an external load that was equivalent to 80% 1RM in the HPC, 30% 1 RM in the BBT and with BM only in the JS.

CHAPTER FOUR

Experiment 2

Complex Training in Professional Rugby Union Players: Influence of Recovery Time on Upper and Lower Body Power Output

INTRODUCTION

Rugby union can be characterized as a field based high intensity collision sport where players are required to perform activities of short duration and high intensity separated by recovery periods of varying duration. The nature, frequency and duration of the work and recovery periods can vary significantly depending on player position (Deutsch et al., 2007). For example, it has been calculated that the average frequency of sprints per game ranged from 8 ± 6 for front row players to 13 ± 5 for outside backs and the average frequency of tackles per game was 13 ± 5 for back row players and 7 ± 4 for outside backs (Duthie et al., 2005). Based this work by Duthie et al. (2005) it is clear that rugby players are required to perform activities along the strength and power continuum with some activities classed as low force – high velocity (e.g. sprinting, accelerating and rapid changes of direction), some classed as high force – low velocity (e.g. Scrummaging, mauling) and finally activities such as tackling can be classed as high force – high velocity. Based on the multifaceted demands of the game of rugby the development of strength and power are fundamental to success in this sport.

Investigations have been conducted to examine various training protocols purported to enhance power development in athletes. These training methods have included athletes trying to develop power while working against their body mass (e.g. plyometrics) and also while working against external loads that equate to various intensities of their 1 RM (40-70% during upper body exercises (Baker et al., 2001 and Newton et al., 1997), body mass - 60% for lower body exercises (Izquierdo et al., 2002 and Stone et al., 2003) and 80-100% for Olympic-style weightlifting movements (Kawamori et al., 2005 and Chapter 3).

More recently, a method receiving significant attention called complex training has been suggested to be an effective training method for enhancing power output in athletes (Baker, 2003). Complex training alternates a heavy resistance exercise (HRT) with a biomechanically comparable plyometric exercises in the same workout (Jones & Lees, 2003) with the intention of increasing the power output during the plyometric exercise. In addition, this method may have even greater application for rugby players who frequently have to generate force against a range of contrasting loads.

Research examining the effectiveness of complex training has produced contradictory results. For example, following heavy resistance training (HRT) (>80% 1 RM) subsequent muscle performance has been demonstrated to decrease (Ebben et al., 2000 and Jones & Lees, 2003) while other studies have reported increases in performance (Baker, 2003 and Chiu et al., 2003). The observed decrease in performance can be attributed to muscle fatigue associated with the HRT (e.g. low intramuscular stores of phosphocreatine) while the increase in muscle performance observed has been attributed to a condition referred to as postactivation potentiation (PAP)

(Gullich & Schmidtbleicher, 1996). Based on the above statement it is clear that both fatigue and PAP can coexist in skeletal muscle, and muscle performance following HRT depends on the balance between muscle fatigue and muscle potentiation (Rasier & MacIntosh, 2000).

This conflict in the literature regarding an athlete's ability to harness PAP can be explained by the numerous methodological differences in the various studies, which include the magnitude of the preload, previous weight training experience, and strength levels of the subjects (Hodgson et al., 2005). While the majority of these methodological variations can be controlled for, there is no uniform agreement about the optimal recovery time between the HRT and subsequent explosive activity, with studies reporting recovery periods ranging from 0 to 18.5 min (Young et al., 1998; Duthie et al., 2002; Baker, 2003; Chiu et al., 2003; Jensen & Ebben, 2003; Brandenburg, 2005 and Comyns et al., 2006). To date, there has been a limited number of studies that have attempted to directly examine the optimal recovery time between the HRT and subsequent explosive activity (Comyns et al., 2006 and Jensen & Ebben, 2003), both focused on lower body performance and utilised relatively short recovery periods, which may indicate that greater than 6 min of recovery may be needed to see a performance enhancement

In addition, the majority of studies have concentrated on the effects of PAP on lower body performance (e.g. jumping ability) (Gullich &

Schmidtbleicher, 1996; Wilson et al., 1993 and Young et al., 1998); however, more recently, researchers have started to investigate the effectiveness of complex training on upper body performance (Baker, 2003 and Baker & Newton, 2005). For example, (Baker, 2003) reported significant improvements in bench press throw performance of 4.5% following a set of 6 reps at 65% of the subjects 1 RM.

Kilduff et al 2007 demonstrated that both upper and lower body performance can be enhanced by utilising a preload stimulus consisting of 1 set of 3 repetitions at 91% RM providing sufficient (8 – 12mins) recovery is given. However studies investigating a more typical complex training protocol have been equivocal

Therefore, in light of the above, the aim of the present study was to determine the recovery time for maximal benefits between the HRT (3 sets of 3 repetitions at 87% 1 RM) and subsequent upper and lower body explosive performance in a group of professional rugby players.

METHODS

Subjects

Twenty-six professional rugby players (Table 4.1) from whom written informed consent had been obtained, volunteered to take part in the present study which was approved by the university ethics committee and carried out during the pre-season (August – September). Subjects were recruited on the basis that they were engaged in structured weight-training programs for at least 2 years prior to the start of the study and were able to complete the bench press, back squat, ballistic bench throw (BBT) and countermovement jump (CMJ) with correct technique as assessed by a qualified strength and conditioning coach. Injury, technical competence and availability limited the number of subjects to twenty for the lower body section of the study. The average resistance training experience of the present group of subjects was 3.1 ± 1.6 years.

Experimental Procedures

Prior to the commencement of the main experimental trial, subjects visited the laboratory in order to become familiar with the testing methods and to have their 3 RM Bench Press and Back Squat measured. During this familiarisation session subjects also practised performing both the BBT and CMJ with the aim to maximise throw and jump height. In addition, all subjects in the present study had previously participated in an optimal loading for peak power output using the BBT and CMJ methods and were therefore well familiarized with the testing methods. Forty-eight hours after the familiarisation and strength testing period, all subjects performed the upper body section of main experimental trial and 48 hours after that they performed the lower body section

Subjects reported to the laboratory on the morning of testing after having refrained from alcohol, caffeine and strenuous exercise for 48hr before. Following the measurement of each subject's stature and body mass, subjects underwent a standardized warm-up which comprised of 5 min on a rowing ergometer, followed by a series of dynamic stretches with an emphasis on stretching either the musculature associated with the Bench Press and BBT or Squat and CMJ. Following the warm-up subjects completed a baseline BBT or CMJ. After a recovery period subjects completed the Heavy Resistance Training (HRT), Bench Press or Squat. Immediately following the HRT (within 15 s) and every 4 min after the HRT up to and including 24 min (e.g. at 4, 8, 12, 16,2 and 24 min) the subjects repeated the BBT or CMJ.

Consumption of water (500 mls) was permitted during each test. Room temperature was maintained between 20-24 °C. Verbal encouragement was given to maximize performance.

Table 4.1: Physical Characteristics of Subjects at baseline (n = 26)

Variables	**Mean ± SD**
Weight (kg)	99.1 ± 12.2
Stature (cm)	184 ± 8
Age (dec.yrs)	25.5 ± 4.8
1RM Bench Press (kg)*	134 ± 13
1RM Squat (kg)*	201 ± 41
Professional Rugby Experience (yrs)	4.8 ± 2.7

Values are Mean ± SD.
* Estimated from their 3RM Strength Testing (Baechle & Earle, 2000).

Measurements

Strength Testing

Prior to the start of the strength testing session, all subjects underwent a standardized warm-up which comprised of light intensity rowing for 5 min, followed by a series of dynamic movements with an emphasis on warming up the musculature associated with the Bench Press or Squat Subjects then performed 3 warm-up sets of 8 repetitions at 50% 1 RM, 4 repetitions at 70% 1 RM and finally 2 repetitions at 80% of their 1 RM. Following the final warm-up set, subjects attempted 3 repetitions of a set load (3 RM) and if successful, the lifting weight was increased until the subject could not lift the weight through the full range of motion. All subjects had been previously exposed to 3 RM testing for the Bench Press and Squat. A 5 min rest was imposed between all attempts to allow subjects adequate time to replenish energy stores. The 3 RM was determined after 3-4 attempts in all subjects. The bench press and Squat movement was carried out according to the International Powerlifting Federation rules (2007).

Ballistic Bench Throw (BBT)

For the measurement of upper body power subjects completed BBT on a smith machine with the ballistic measurement system attached. Upper body peak power output (PPO) was tested during a BBT performed on a smith machines with a relative resistance of 30% of their predicted 1 RM which has previously been shown to be the optimal load for developing PPO in the upper body in rugby players in our laboratory (Chapter 3). During each BBT the subject was instructed to lift the bar from the starting position and throw it as high as possible. To avoid the effects of deceleration and achieve maximal bar velocity, the bar was released at the top of the range of motion. During each throw, subjects were required to keep their head, shoulders, and trunk in contact with the bench as well as their feet in contact with the floor.

Subjects completed 8 BBT at the following times: baseline, immediately after preload stimulus (~15 s) and then every 4 minutes up to and including 24 min. In order to ensure that any effect observed during this experiment was due to the HRT 10 subjects where required to complete 7 BBT following a standardised warm-up with 4 min recovery between each one. This was carried out to ensure that during the main experimental trial there was no warm-up effect or fatigue effect from the subsequent BBT. A repeated measures one-way analysis of variance revealed no significant time effect over the duration of the study (Effect size eta^2=0.78, p =0.759). The HRT consisted of 3 sets of 3 repetitions at 87% of the subjects estimated 1 RM on the bench press with 4 min recovery between each set and was performed ~15 min after the baseline BBT.

Ballistic Measurement System (BMS)

The BMS was used to collect bar displacement data during the BBT. Peak Power Output (PPO) and throw height from the BBT were calculated using the software provided with the BMS. The BMS comprises a cable-extension potentiometer (distance transducer) that produces a variable voltage output in relation to the extension of the 3-m cable. An analogue to digital card then captured the voltage data, with customized software, sampling at 500 Hz, converting the voltage data into displacement data. The BMS system was calibrated against known distances for the range on which the BBT were performed; this calibration was performed before all testing sessions. The reliability of the BMS has been assessed for the measurement of PPO during the BBT in a study by Alemany et al. (2005). In this study the authors reported a strong intraclass correlation coefficient (r=0.93) for peak power obtained during the BBT.

Countermovement Jump (CMJ)

For the measurement of lower body power, subjects completed CMJ on the portable force platform. In order to isolate the lower limbs, subject's stood with arms akimbo (Aragon-Vargas & Gross, 1997; Hatze, 1998). After an initial stationary phase of at least 2 s, in the upright position, for the determination of body weight, the subject's performed a CMJ, dipping to a self-selected depth and then exploding upwards in an attempt to gain maximum height. Subject's landed back on the FP and their arms were kept akimbo throughout the movement. Subject's completed 8 CMJ at the following times: baseline, immediately after preload stimulus (~15 s) and then every 4 minutes up to and including 24 min. The HRT consisted of 3 sets of 3 repetitions at 87% of the subjects estimated 1 RM on the squat with 4 min recovery between each set, and was performed ~15 min after the baseline CMJ.

Force Platform

A Kistler portable force platform with built-in charge amplifier (type 92866AA, Kistler Instruments Ltd, Farnborough, UK) was used for data collection of the ground reaction force (GRF) time history of the CMJ. A sample rate of 1000 Hz was used for all jumps and the platform's calibration was confirmed pre and post testing.

Data Analysis

The vertical component of the GRF as the subject performed the CMJ was used in conjunction with the subject's body weight to determine the instantaneous velocity and displacement of the subject's centre of gravity (CG) (Hatze, 1998). Instantaneous power was determined using the following standard relationship:

Power (W) = vertical GRF (N) x vertical velocity of CG ($m.s^{-1}$)

In order to determine the velocity of the subject's CG numerical integration was performed using Simpson's rule with intervals equal to the sample width. Prior to the calculation of the strip area, the subject's body weight (as measured in the stationary phase) was subtracted from the GRF values. The area of the strip, of width equal to the sample rate, then represented the impulse for that time interval. Using the relationship that impulse equals change in momentum; the strip area was then divided by the subject's mass to produce a value for the change in velocity for the centre of gravity (it was assumed that the subjects mass remained constant throughout the jump). This change in velocity was then added to the CG's previous velocity to produce a new velocity at a time equal to that particular intervals end time. This process was continued throughout the jump. As this method can only determine the change in velocity it was necessary to know the CG's velocity at some point in time. For this purpose, the velocity of the CG was taken to be zero prior to the initiation of the jump (during the period of body weight measurement) and specifically at the point identified as the start of the jump. The start point was defined as the time when the subject's GRF exceeded the mean ± 5 standard deviations from the values obtained in the second (of the stationary body weight measuring phase) immediately prior to the command to jump, in a fashion similar to Vanrenterghem, DeClercq & Van Cleven (2001). Integration started from this point.

Vertical displacement was determined by a second integration. The instantaneous velocity time history was numerically integrated (in the same way as described above) from the start point of the jump. The height (vertical displacement) of the centre of gravity at the start point of the jump was defined as zero. Jump height was then defined as the difference in the vertical displacement of the CG, between take off (toes leave the force plate) and maximum vertical displacement achieved.

Instantaneous rate of force development (RFD) was calculated from the first derivative of the vertical GRF. Prior to numerical differentiation the vertical GRF was filtered using a dual pass Butterworth filter (low pass, 10Hz cut off). Filter settings were determined from a pilot study and based on Fourier analysis and inspection. Peak RFD (PRFD) was taken as the highest RFD during the concentric or eccentric phase of the jump. The concentric phase was defined as succeeding the point that the instantaneous velocity of the CG equalled zero after the initiation of the jump. Test-retest reliabilities (ICC's) for PO, PRFD and maximum jump height were; 0.979, 0.890 and 0.976, respectively.

Statistical Analysis

Following a test for the normality of distribution, data was expressed as the mean ± S.D. Statistical analysis was carried out using a repeated measures one-way analysis of variance (ANOVA) to determine whether PPO and maximum throw height or jump height changed throughout the testing session. When significant F values were observed ($P \leq 0.05$), paired comparisons were used in conjunction with Holm's Bonferroni method for control of type I error to determine significant differences. A Pearson correlation analysis was used to assess the relationship between strength and changes in PPO following potentiation.

The level of significance was set at $p \leq 0.05$ in the present study and all statistics were performed using SPSS 13.1 (SPSS Inc., Chicago, IL)

RESULTS

Bench Press Throw (BBT)

Peak Power Output (PPO)

A repeated measures ANOVA revealed a significant time effect over the duration of the study ($F=29.145$, Effect size $eta^2=0.538$, $p < 0.05$) with follow up paired comparisons indicating a significant decrease in PPO in the BBT performed ~15 s after the HRT compared to the baseline BBP (Figure 4.1a). Following 4 min of recovery PPO returned to a similar value to baseline with no significant difference between these two values (Baseline: 879 ± 20 vs. 4 min: 878 ± 22 W, $P>0.05$). Subjects in the present study produced their maximum PPO following 8 min of recovery from the HRT, and this power output was significantly higher than the power outputs at all other time points except the 12 min (Figure 4.1a). There was no significant difference between the PPO at 12, 16, 20 or 24 min when compared to the baseline values (Figure 4.1a).

Throw Height

The repeated measures ANOVA revealed a significant time effect on throw height ($F=17.362$, Effect size $eta^2=0.410$, $p < 0.001$). Maximum throw height during the BBP was observed following 8 min of recovery from the HRT and this was significantly higher when compared to throw height recorded at baseline (35.3 ± 1.4 vs. 37.2 ± 1.4 cm, $p < 0.01$), 16, 20 and 24 min time point (Figure 5.1b). There was no significant difference between the throw height at 8 min compared to the throw height at 12 min (37.2 ± 1.4 vs. 36.5 ± 1.3 cm, $P > 0.05$). When the players performed the BBP immediately (~15 s) after the HRT their throw height was significantly reduced compared to their baseline BBT (31.7 ± 1.2 vs. 35.3 ± 1.4 cm, $p < 0.01$) (Figure 4.1b).

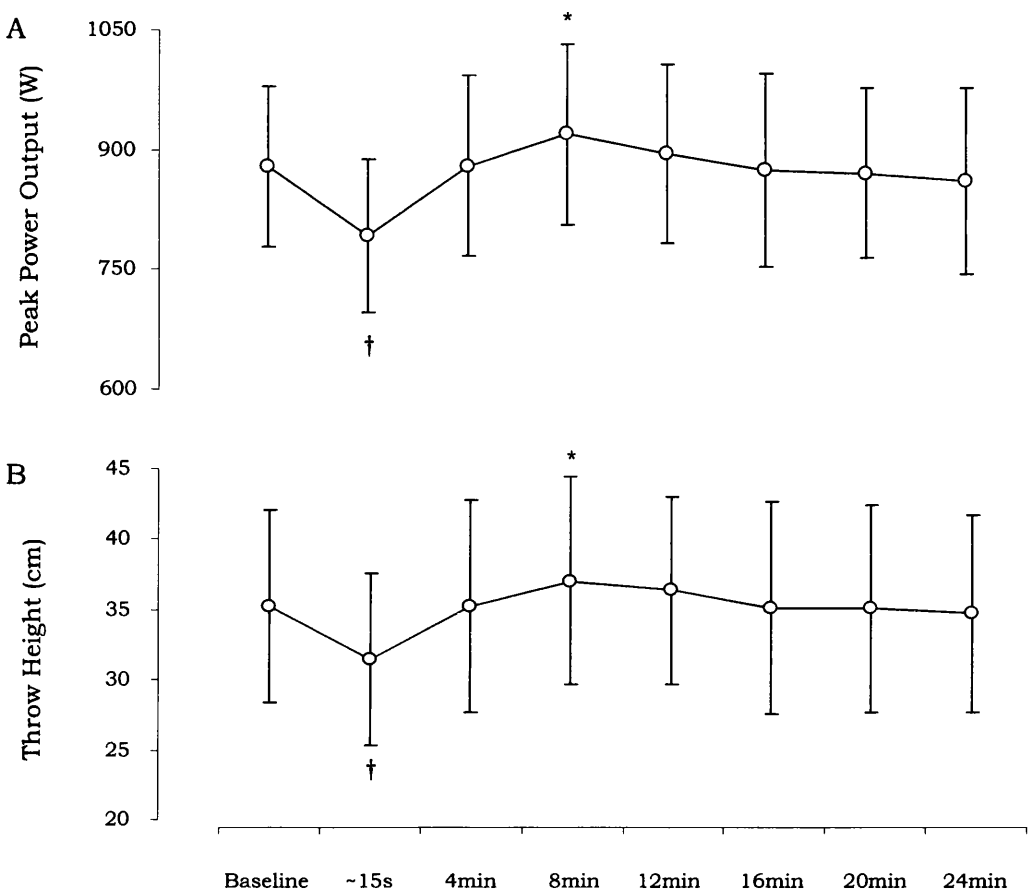

Figure 4.1: Peak Power Output (A) and Throw Height (B) during Ballistic Bench Throws before & after Heavy Resistance Training
†: Indicates significant decrease compared to baseline
*: Indicates significant increase compared to all other time points

Countermovement Jump

Peak Power Output (PPO)

A repeated measures ANOVA revealed a significant time effect over the duration of the study (F=11.044, ES=0.368, $p < 0.05$) with follow up paired comparisons indicating a significant decrease in PPO in the CMJ performed ~15 s after the HRT compared to the baseline CMJ (Figure 4.2a). Following 4 min of recovery PPO returned to a similar value to baseline with no significant difference between these two values (Baseline: 5347 ± 148 vs. 4 min: 5407 ± 142 W, P>0.05). Subjects in the present study produced their peak power output (PPO) following 8 min of recovery from the HRT and this power output was significantly higher than the power outputs at all other time points (Figure 4.2a). There was no significant difference between the PPO at 12, 16, 20 or 24 min when compared to the baseline values (Figure 4.2a).

Peak Rate of Force Development (PRFD)

In terms of PRDF, the ANOVA indicated a significant change in PRFD (F=10.488, ES=0.356, $p < 0.001$) over time. PRFD following the HRT (~15 s) was reduced but not significantly compared to baseline (11587 ± 878 vs. 12358 ± 673 $N \cdot s^{-1}$, P>0.05). Following this initial decrease PRFD returned to values similar to baseline (13249 ± 827 vs. 12358 ± 673 $N \cdot s^{-1}$, P>0.05) with the values for PRFD reaching maximum at the 8 min time point. The PRFD at the 8 min time point was significantly higher than those obtained at the baseline time point (16290 ± 810 vs. 12358 ± 673 $N \cdot s^{-1}$, $P>0.05$) and all other time points (Figure 4.2b).

Jump Height

The repeated measures ANOVA revealed a significant time effect on jump height ($F=19.633$, $ES=0.508$, $p < 0.001$). Maximum jump height during the CMJ was observed following 8 min of recovery from the HRT and this was significantly higher when compared to jump height recorded at baseline (34.3 ± 1.2 vs. 36.0 ± 1.2 cm, $p < 0.01$). In addition, the height jumped at the 8 min time point was significantly higher than the jump height at any other time point throughout the study (Figure 4.2c). When the players performed the CMJ immediately (~15 s) after the HRT their jump height was significantly reduced compared to their baseline jump (32.4 ± 1.2 vs. 34.3 ± 1.2 cm, $p < 0.01$) (Figure 4.2c).

Additional Analysis

A significant positive correlation was found between 3 RM strength and delta potentiation at the 8 min time point for both upper (PO at 8 min – PO at baseline; r=0.520, p =0.006, n=26) and lower PPO (PO at 8 min – PO at baseline; $r=0.489$, $p=0.029$, $n=20$). Results showed that 15 subjects (58%) obtained their highest PPO at the 8 min time point. While 7 subjects obtained their peak at 12 min, 3 subjects at 16 min while 1 subject produced their best results after only 4 min recovery in terms of upper body PPO. With regard to lower body PPO, 14 subjects (70%) obtained their highest PO, PRFD and jump height at the 8 min time point. While 3 subjects obtained their peak at 12 min, the final 3 subjects produced their best results after only 4 min recovery.

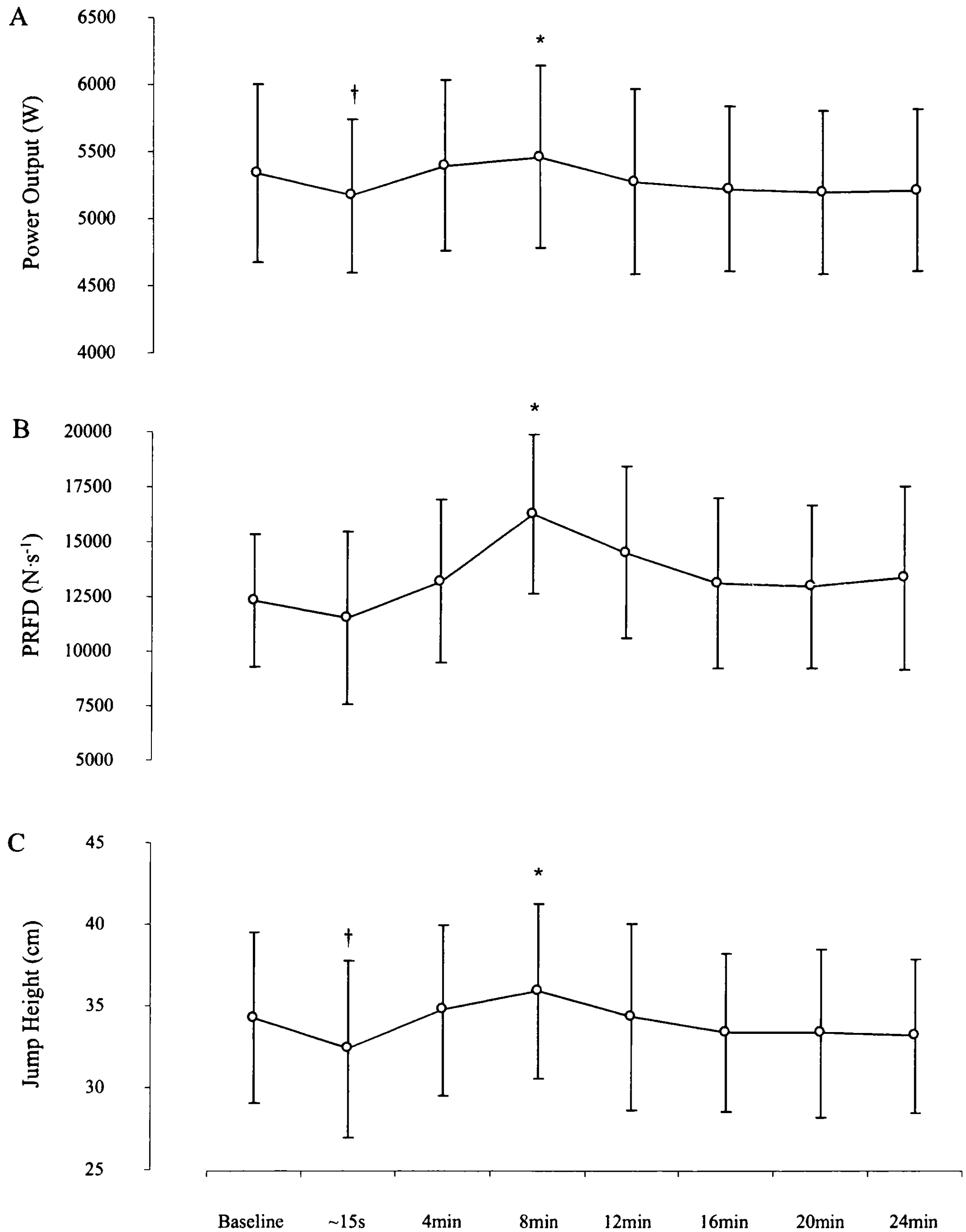

Figure 4.2: Power Output (A), PRFD (B), and Jump Height (C) during Countermovement Jumps before & after Heavy Resistance Training
†: Indicates significant decrease compared to baseline
*: Indicates significant increase compared to all other time points

DISCUSSION

The results of the present study indicate that on average 8 min recovery is required between the HRT and subsequent explosive performance in order to observe enhanced power output in the either the upper or lower body in a group of professional rugby players (Figures 4.1 & 4.2). In addition, the present study highlights that when the explosive activity was performed immediately after (~15 s) the HRT performance was decreased compared to the same exercise performed with no HRT (Figures 4.1 & 4.2).

The primary aim of the present study was to determine the recovery period required to observe enhanced power output during the BBT and CMJ following a bout of HRT in a group of professional rugby players. Previous studies examining the effectiveness of HRT on subsequent explosive muscle performance have used recovery periods ranging from 0 to 18.5 min (Young et al., 1998; Baker, 2003; Chiu et al., 2003; Gourgoulis et al., 2003; Jensen & Ebben, 2003; Brandenburg, 2005 and Comyns et al., 2006) with no uniform agreement to date on the optimal time required. The majority of the studies have used recovery periods of approximately 4 min, presumably to allow for PCr resynthesis following the HRT (Young et al., 1998; Baker, 2003; Brandenburg, 2005 and Comyns et al., 2006). In the present study when we allowed 4 min recovery between the HRT and the BBT we found no significant difference between this time point and baseline which probably reflects the replenishment of PCr stores following the HRT Nevill et al. (1997) which is in agreement with the findings of Jensen and Ebben (2003). This finding is supported by the early findings of Gullich and Schmitbleicher (1996), who found an initial depression in H-reflex activity following a preload stimulus with the H-reflex amplitude returning to levels similar to baseline after 4 min recovery.

To date, only a few studies have directly examined the effect of varying recovery times on subsequent muscle performance (Comyns et al., 2006 and Jensen & Ebben, 2003) both of which examined lower body performance with no study to date examining this in relation to upper body performance, despite the important of upper body power to many sports. Jensen & Ebben (2003) used various recovery periods (10 s, 1, 2, 3 and 4 min) and reported no significant difference between the power outputs at any of the time points after the preload stimulus compared with the power output performed before the preload. However, the authors did report a non-significant trend towards an improvement in performance and concluded that greater than 4 min of recovery might be required to enhance performance. Similarly, Comyns *et al.* (2006) reported no significant enhancement in jump performance following HRT, but again used relatively short recovery periods (30 s, 2, 4, and 6 min) between the HRT and explosive activity.

In addition, only two studies have examined the effectiveness of longer than 6 min recovery between the HRT and subsequent explosive exercise (Chiu *et* *al.*, 2003 and Jones & Lees, 2003). Jones and Lees (2003) reported no significant change in CMJ performance following 3, 10 or 20 min recovery after a set of heavy squats compared to the baseline CMJ performed before the heavy squats. However, the sample size of this study was small (n=8) and as indicated by the author's, some trends in the data were present, but the power of the statistical analysis was low. Chiu *et al.* (2003) reported that average force, average power and peak power were significantly greater at 18.5 min postactivation compared to 5 min postactivation. However, as measurements were only taken at these time points, the optimal recovery period could be anywhere between 5 and 18.5 min.

The results of the current study help clarify the recovery period needed in order to achieve maximal increases in both BBT and CMJ performance in well-trained athletes. Our results indicate that 8 min of recovery is required to achieve maximal increases in PO, maximum throw height, maximum jump height and PRFD. Findings which are supported by Gullich and Schmitbleicher (1996) in that they reported the greatest increase in H-reflex activity (32%) following their HRT occurred after a 8.7 ± 3.6 min recovery period which lead to a significant enhancement of explosive force production in plantar flexions following this recovery period.

Furthermore, 70% of the subjects performed their best jump at the 8 min time point with the remaining 30% performing better at the 4 min (15%) and 12 min (15%) time points similarly 15 subjects (58%) performing their best BBT at the 8 min time point and the remaining 42% performing better at the 4 min (1 subject), 12 min (7 subjects) and 16 min (3 subjects) time points. This finding indicates that individual determination of the optimal recovery rest interval might be necessary as suggested by Comyns et al. (2006).

As electromyography recording were not obtained in this study, we can only speculate on the potential mechanism for the observed improvement in performance following PAP. However, two primary theories have been proposed to date: (1) the preload stimulus acts to enhance motor-unit excitability, possibly affecting a number of processes such as increased motor unit recruitment, increased motor unit synchronization, decreased presynaptic inhibition or greater central input to the motor neuron; and (2) enhanced phosphorylation of the myosin light chain (MLC), where the preload causes an increase in sarcoplasmic $Ca2+$ which activities MLC kinase which in turn increases actin-myosin cross bridging (Hodgson et al., 2005).

Despite the majority of PAP studies showing an ergogenic effect on performance, for example (Baker, 2003 and Goosen & Sale, 2000), there are still a significant number of studies that report no ergogenic effect (Brandenburg, 2005). As indicated in the review by Hodgson et al. (2005) training history and/or strength levels of the subjects seem to be important factors in the outcome of PAP studies. Studies to date have used subjects of varying strength levels (from recreationally trained to power athletes) and in some studies it was only when subjects were differentiated into "strong" and "weak" subjects based on their strength levels (Baker, 2003) or training experience (Chiu et al., 2003) that a performance effect was observed. For example, Chiu et al. (2003) initially reported no change in performance following a preload stimulus when the group were considered as a whole; however, once the group was divided on the basis of strength, performance increases were observed.

In support of this, the studies by Young et al. (1998) and Duthie et al. (2002) found significant correlations between performance changes following the preload stimulus and measures of strength (e.g. 1 RM) (r=0.73 and r=0.66, respectively) which indicated that stronger subjects had greater potential for performance gains following HRT. Results from the present study also show a positive correlation between the subjects strength (3 RM) level and the change in performance following potentiation. This relationship suggests that stronger individuals have greater potential to increase BBT and CMJ performance. While the exact reason behind this relationship between strength and potentiation remains unclear it has been demonstrated that resistance trained athletes have greater activation of the musculature involved during HRT, which would affect the H-reflex and myosin regulatory light chain phosphorylation the 2 mechanisms involved in the PAP phenomenon (Aagaard et al., 2002). In addition, Gullich & Schmitbleicher (1996) reported differences between speed-strength athletes (highly trained) and sports students (trained) in that the highly trained athletes showed a significantly higher and longer lasting potentiation effect compared to the less trained sports students. In addition, this study reported differences between the level of potentiation between the soleus muscle (predominantly slow-twitch muscle fibre) and the gastronomies muscle (predominantly fast-twitch muscle fibre); with the gastronomies muscle having a greater level and longer lasting potenitiaton effect compared to the soleus muscle.

Despite the present study showing a positive effect of PAP on BBT and CMJ's in our group of professional rugby players, it is still to be determined whether PAP can be harnessed to improve power production in the more complex tasks involved in rugby such as sprinting, tackling and scrummageing. In addition, individual determination of the optimal recovery time required for enhanced performance following HRT is required and is supported by the findings of Gullich and Schmitbleicher (1996) who reported the time course of the athlete's highest reflex response showed considerable interindividual variation.

In conclusion, the results from the present study indicate that muscle performance (e.g. power) is enhanced following HRT in both the upper body and lower body providing adequate recovery is given between the two activities. In addition, the athlete's initial strength level plays in important role in their ability to utilize this PAP phenomenon.

CHAPTER FIVE

Experiment 3

Influence of Postactivation Potentiation on Sprinting Performance in Professional Rugby Union Players

INTRODUCTION

In the previous two chapters we sought to investigate the optimal conditions in order to observe an enhancement in muscle performance following a pre-load stimulus. For example, in Chapter 4 and in Kilduff et al. (2007) we demonstrated that the optimal recovery time to observe enhanced performance following a pre-load stimulus and have reported that between 8 - 12 min recovery is required between the pre-load stimulus and the explosive activity. However although we now have a better understanding of the exact experimental design required to observe enhanced performance with PAP during squat jumps and ballistic bench throws (Chapter Four), research still needs to be carried out to see if PAP can be harnessed to enhance performance in more functional activities such as sprinting.

Therefore, due to the lack of research regarding PAP and its effect on activities directly transferable to sport, the aim of the present study was to investigate the effects of a pre-load stimulus on 5 and 10m sprint times of professional rugby players.

METHODS

Experimental Approach to the Problem

During this within subject design study each subject was required to attend the laboratory on 2 occasions. The objective of the first testing session was to determine the subjects 3 RM on the squat and familiarize the subjects to the study procedures that were to follow. During the main experimental trial, subjects completed a baseline 10 m sprint (with 5 m split), then following a 20 min recovery period, subjects were required to complete 1 set of a pre-load stimulus (1 set of 3 repetitions at 91% of the subjects estimated 1 RM in the Back squat. Following the pre-load stimulus subjects completed a 10 m sprint (with 5 m split) every 4 minutes up to and including 16 min (4, 8, 12, 16 min).

Subjects

Sixteen professional rugby players (Table 5.1) from who written informed consent had been obtained, volunteered to take part in the present study which was approved by the a local ethics committee and carried out during the pre-season (August – September). At the time of entry into the study subjects that completed a power phase which incorporated Olympic lifts, the various derivates of the Olympic lifts, and complex/contrast exercises (including sprinting). The average resistance training experience of the present group of subjects was 2.1 ± 1.4 years.

Table 5.1: Physical characteristics of subjects at baseline (n = 16)

Variables	Mean ± SD
Mass (kg)	103.0 ± 12.6
Stature (cm)	184.6 ± 6.3
Age (yrs)	25.0 ± 4.8
1RM Squat (kg)	170.3 ± 17.3

Experimental Procedures

Prior to the commencement of the main experimental trial, subjects visited the laboratory in order to become familiar with the testing methods and to have their 3 RM squat measured. Forty-eight hours after the familiarisation and strength testing period, all subjects performed the main experimental trial.

Subjects reported to the laboratory on the morning of testing after having refrained from alcohol, caffeine and strenuous exercise for 48hr before. Following the measurement of each subject's stature and body mass, subjects underwent a standardized warm-up which comprised of progressive 10 m sprints with players performing dynamic mobility exercise at set intervals throughout the warm-up with an emphasis on warming-up the musculature associated with the squat and sprinting. Following the warm-up subjects completed a baseline 10 m sprints (with 5 m split). After a 20 min recovery period subjects completed the pre-load stimulus on the Squat. Following 4, 8, 12 & 16 min of recovery from the preload stimulus players completed 10m sprint (with 5m split). In order to ensure that any effect observed during this experiment was due to the pre-load stimulus 10 subjects where required to complete 4 10 m sprints following a standardised warm-up with 4 min recovery between each one. This was carried out to ensure that during the main experimental trial there was no warm-up effect or fatigue effect from the subsequent 10 m sprint. A repeated measures one-way analysis of variance revealed no significant time effect over the duration of the study ($F= 1.382$, Effect size $eta^2= 0.090$, $P = 0.252$).

Consumption of water (500 mls) was permitted during each test. Room temperature was maintained between 20-24 °C. Verbal encouragement was given to maximize performance.

Measurements

Strength Testing

Prior to the start of the strength testing session, all subjects underwent a standardized warm-up, which comprised of light intensity rowing for 5 min, followed by a series of dynamic movements with an emphasis on warming up the musculature associated with the Squat. Subjects then performed 3 warm-up sets of 8 repetitions at 50% 1 RM, 4 repetitions at 70% 1 RM and finally 2 repetitions at 80% of their 1 RM. Following the final warm-up set, subjects attempted 3 repetitions of a set load (3 RM) and if successful, the lifting weight was increased until the subject could not lift the weight through the full range of motion. All subjects had been previously exposed to 3 RM testing for the Squat. A 5 min rest was imposed between all attempts to allow subjects adequate time to replenish energy stores. The 3 RM was determined after 3-4 attempts in all subjects. The Squat movement was carried out according to the International Powerlifting Federation rules (2007).

5 & 10 m Sprint Performance

Timing gates (Brower Timing Systems, Utah, USA) were set up at 0, 5 and 10 m positions to measure 5 and 10 m sprint times. Subjects started each sprint from a standard two point starting position with the subjects front foot placed on a line 30 cm behind the first set of timing gates. This procedure was carried out to ensure the subjects didn't set off the timing gates prior to the start of each sprint. The timing gates were set at a height of approximately 80cm off the ground (around hip height), which from previous experience was necessary to minimise the chance of light beams being broken by the lower leg or lower arm during the sprinting action.

Subjects completed five 10 m sprints at the following times: baseline, 4, 8, 12 & 16 min after the pre-load stimulus. The preload stimulus consisted of 1 set of 3 repetitions at 91% of the subject's estimated 1 RM on the squat. Test-retest reliabilities (ICC's) for 10m sprints were 0.976.

Statistical Analysis

Following a test for the normality of distribution, data was expressed as the mean ± S.D. Statistical analysis was carried out using a repeated measures one-way analysis of variance (ANOVA) to determine whether sprinting performance changed throughout the testing session. When significant F values were observed ($P \leq 0.05$), paired comparisons were used in conjunction with Holm's Bonferroni method for control of type I error to determine significant differences. A Pearson correlation analysis was used to assess the relationship between strength and changes in PPO following potentiation.

The level of significance was set at $p \leq 0.05$ in the present study.

RESULTS

5 & 10 m Sprint times

A repeated measures ANOVA revealed no significant time effect over the duration of the study with regard to 5 m (F= 1.650, ES= 0.105, p = 0.175) and 10 m sprint times (F= 1.028, ES Effect size eta^2= 0.068, p = 0.401).

However based on previous research completed in this thesis (Chapter 4 & Kilduff et al., 2007) on the influence of recovery time on PAP we reported large intra-individual responses with regard to the optimal recovery between the pre-load stimulus and the subsequent explosive activity. Based on this research we examined the current data for individual response to PAP.

With regard to 5 m sprint time 47% of the subjects performed their best 5 m sprint 8 min following the pre-load stimulus, 27% following 12 min and 13% at 4 and 16 min. A paired sample t-test revealed a significant decrease in sprint time over 5 m following the subjects best 5 m sprint following the pre-load stimulus compared to baseline (Baseline: 1.09 ± 0.06s vs. Best time: 1.05 ± 0.05s, p =0.007) (Figure 5.1 & 5.2).

A similar finding when comparing 10 m sprint times at baseline compared to the best 10 m sprint time following the pre-load stimulus

(Baseline: 1.83 ± 0.08s vs. Best time: 1.79 ± 0.08s, $p = 0.003$) (Figure 5.1 & 5.2). Similarly to 5m results, a majority of subjects (53.3%) performed their best sprint times at the 8-minute time point, with the remainder evenly distributed between the 4 and 16-minute time points.

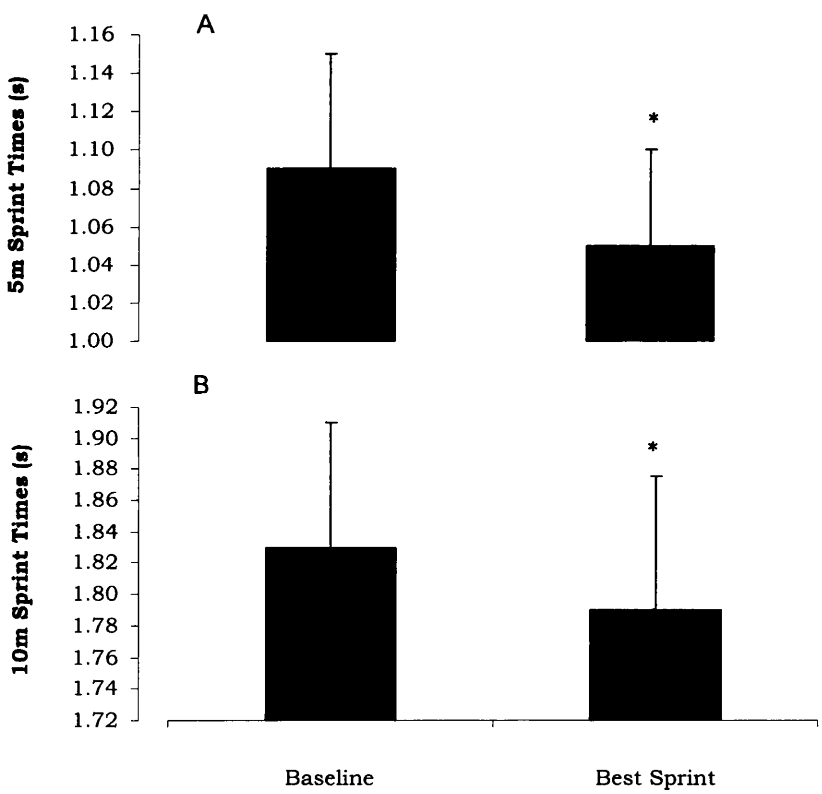

Figure 5.1: 5m (A) and 10m (B) Sprint Times at Baseline and Best Sprint Post-potentiation (N=16)

*: Indicates significant increase compared to baseline

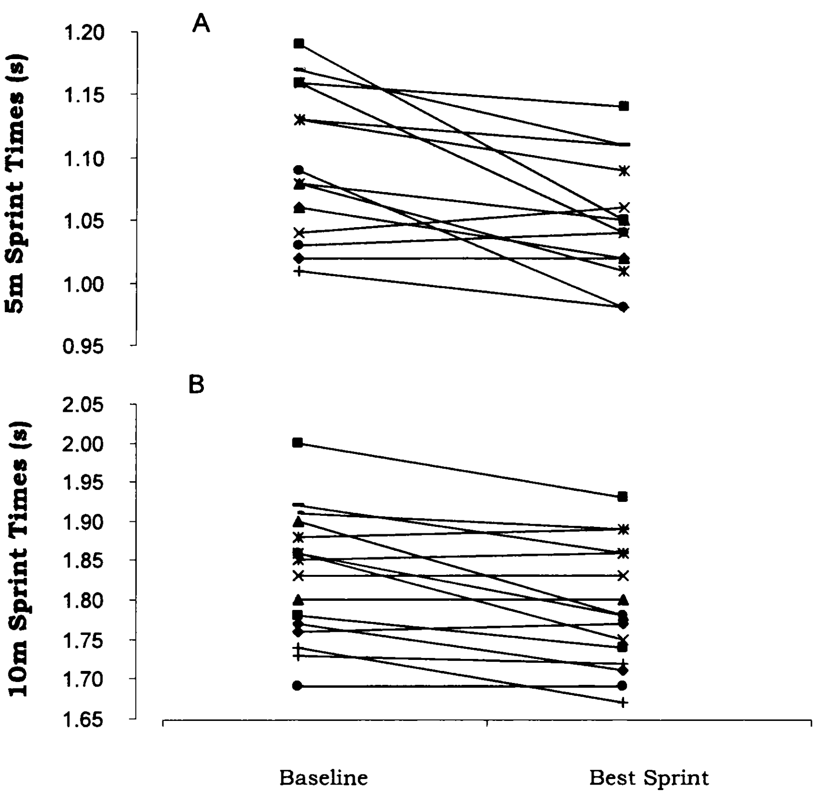

Figure 5.2: 5m (A) and 10m (B) Sprint Times at Baseline and Best Sprint Post-potentiation (N=16)

DISCUSSION

The results of the present study demonstrate that PAP can be harnessed to enhance sprinting performance in professional rugby players providing adequate and individualised recovery is given between the pre-load stimulus and subsequent sprint activity (Figure 5.1 & 5.2).

In the present study, the subjects observed a 5.0 ± 1.0% and 8.0 ± 1.0% improvement in sprint performance over 5 (Baseline: 1.09 ± 0.06s vs. Best time: 1.05 ± 0.05s, $p \leq 0.007$) and 10m (Baseline: 1.83 ± 0.08s vs. Best time: 1.79 ± 0.08s, $p \leq 0.003$) respectively compared to baseline following the pre-load stimulus. Previously, we have established the effectiveness of PAP in enhancing performance in professional rugby players performed both the squat jump (Chapter 4 and Kilduff et al., 2007) and ballistic bench press (Chapter 4 and Kilduff et al., 2007) and demonstrated a very individual response in terms of recovery time between the pre-load stimulus and the subsequent explosive activity (Chapter 4 and Kilduff et al., 2007), probably due to the varying strength levels of the subjects within this study. The current study found that the majority of subjects performed their best sprint times 8 minutes post pre-load stimulus (5 m: 46.7%; 10 m 53.3%) and this agrees with previous research performed on lower body and upper body PAP and elite rugby union players (Chapter 4 and Kilduff et al., 2007). This finding is further supported by the findings of Gullich & Schmitbleicher (1996) who reported that the greatest increase in H-reflex activity (32%)

following their pre-load stimulus occurred after 8.7 ± 3.6 min recovery period which lead to a significant enhancement of explosive force production in plantar flexions following this recovery period.

In conclusion, the current study observed improvements in performance in 5 and 10 m sprint following a heavy pre-load stimulus when adequate and individualised recovery was given between the pre-load stimulus and the sprint.

CHAPTER SIX

GENERAL DISCUSSION

The main findings from the series of studies contained within this thesis are as follows:

Chapter 3: The optimal load for generating PPO was 80% of 1 RM during the hang power clean (HPC), 30% of 1 RM during the Ballistic Bench Throw (BBT) and 0% of 1 RM in the Jump Squat (JS).

Chapter 4: When utilizing a typical complex training protocol (3 x 3 @ 87%) on average 8 min recovery is required between the HRT and subsequent explosive performance in order to observe enhanced power output in the either the upper or lower body. Once again, a significant performance decrement was observed when the power activity was performed immediately after HRE with performance only returning to baseline levels after 4 minutes of recovery. In addition this study demonstrated a strong correlation between the strength levels of the athletes and PAP.

Chapter 5: PAP can be harnessed to improve sprint performance providing adequate and individualised recovery is given between the pre-load stimulus and subsequent sprint activity.

With regard to the findings from Chapter 3 they confirm that both the peak power values and the percentage of 1RM that produces the PPO are dependent on the muscle group utilised and the type of lift employed which agrees with the findings of Newton et al. (1993), Baker et al. (2001a), Izquierdo et al. (2002) for Bench Press Throws, Baker et al. (2001b), Izquierdo et al. (2002); Siegel et al. (2002); Sleivert & Taingahue (2002), Bourque & Sleivert (2003), Stone et al. (2003) and Cormie et al. (2007) for Jump Squats and (1993), Haff et al. (2002), Kawamori et al. (2005) and Cormie et al., (2007) for Olympic style lifts. For example, Cormie et al (2007) proposed the optimal load for PPO occurred at different loads for various lifts as a result of the difference in acceleration profiles. They suggest that in ballistic lifts such as the Jump Squat, higher velocities can be achieved and therefore maximum mechanical power output occurs at lighter loads. Conversely, in the Olympic lifts and their derivatives the optimal load is achieved with a higher percentage of 1RM. They suggest that this occurs as a result of their inherent high force, high velocity nature, a view that is supported by both Garhammer (1993), Haff et al. (1997) and Kawamori et al. (2005) who found the optimal load for the hang power clean to be 70% of 1 RM.

The difference between the percentage of 1RM that produces the PPO for JS and BPT, two lifts that are ballistic in nature, may be partially explained by the necessary inclusion of body weight in the calculation of system mass and the subsequent power calculation for the Jump squats. Cormie et al. (2007) suggested that this resulted in PPO occurring at 0% of 1RM which equates to 30% maximal dynamic strength (MDS) MDS = 1RM + (Body weight – shank mass) which is the maximum load that is lifted in a

1RM squat. This compares favourably to the 30% of 1RM that was found to produce the PPO in the BBT in this study, as the load of the barbell in a 1RM bench press represents the maximum load that can be lifted in that movement pattern.

The highest PPO value recorded in this study occurred in the JS at 0% (4750.9 ± 529.4W) followed by the HPC at 80% (4467 ± 477.2W) and then the BBT at 30% (865.4 ± 23W). This agrees with the findings of a study by Cormie et al. (2007) who also identified PPO to occur at 0% in the JS and 80% in the PC. In addition the peak power values they obtained for the power clean (4786.63 ± 835.91 W) were very similar which is unsurprising as the strength levels reported for the two sets of subjects is comparable (Squat 181 ± 24kg and HPC 93-132kg vs 170.38 ± 21.72 kg Squat and 112.50 ± 13.15 kg HPC reported by Cormie et al (2007)). This makes the discrepancy between the PPO values reported in the Jump squat somewhat surprising with Cormie et al. (2007) reporting (6437.14 ± 1046.34 W) which are similar to the values reported by Bourque and Sleivert (2003) (6117 ± 867 W). There are several potential explanations for these differences: The subjects in the Cormie et al. (2007) study were American football players, sprinters or long jumpers, all sports where power is a key component, who you would expect to produce high values. In addition, you would anticipate that they would be familiar with maximal power training methods in particular the Jump squat which Baker et al. (2001b) would suggest may cause specific adaptations that would result in higher PPO values relative to those not experienced in power training. However, the Rugby players in the current study had just finished a phase of power development so could be reasonably expected to have a high level of competence in power training methods themselves. Another potential explanation is the higher average body mass of the Rugby players 101.3 ± 12.8kg Vs 90.08 ± 14.81 kg. Both sets of subjects achieve PPO at 0% 1RM i.e. body mass only, however the rugby players are on average approximately 10kg heavier. As PPO is the product of velocity and load, a reduction in power output would only occur if the increased body mass resulted in a significant reduction in velocity.

For the BBT the power output achieved at 30% 1RM was significantly different to those achieved with 20% and 60% of 1 RM but not 40% and 50%, This finding is supported by research by Mayhew et al. (1992) and Siegel et al. (2002) who reported that PPO was produced at a load that equalled 50% of 1 RM and between 40-60% of 1 RM respectively, Newton et al. (1993) who reported that loads of 30 and 45% of 1RM BP produced the highest power outputs and Baker et al. (2001a) who reported that the highest (mean) peak power output to occurred at a resistance of 70.1± 7.9kg, which represented 55 ± 5.3% of mean1RM Bench Press for the group. However, as there was no difference between the power output achieved with the 70 or 80kg loads and very little difference between the 60 and 80kg loads they suggested that the optimal load should actually be considered to occur between 50 – 60% of 1RM. Once again, the discrepancy in the highest power outputs reported between the current study (873.0 ± 24.21W) and Baker's (588 ± 95W) despite the similar strength levels of the subjects 124 ±19kg Vs 129.7 ± 14.3kg highlights the difficulty of comparing studies with differing methodology, in this case reporting peak as opposed to average power output values. However, the large inter individual differences that are apparent in this study with both the BBT and Hang clean are reinforced by the findings of the Baker et al. (2001a) study and would suggest that the intensity at which PPO is achieved is a unique response and needs be assessed on individual basis. A view supported by Cronin and Sleivert (2005) who suggest that future research should focus identifying optimal loads for specific populations and training activity utilised.

Chapter 4 demonstrated that PAP can be utilised to enhance performance in both upper and lower body power activities following an appropriate preload stimulus providing sufficient recovery time is given. The optimal recovery time to maximize the PAP effect was found to be on average to be 8 mins for both the lower body and upper body. In was also found that when the explosive activity (countermovement jump or bench throw) was performed immediately after (~15 s) the preload stimulus, PPO was decreased compared to the same exercise performed with no preload stimulus. This demonstrates that both fatigue and PAP can coexist in skeletal muscle, a view supported by Rasier & MacIntosh (2003). Secondly, A significant positive correlation was found between 3 RM strength and delta potentiation at the 8 min time point for both upper (PO at 8 min – PO at baseline; $r=0.520$, $p=0.006$, $n=26$) and lower PPO (PO at 8 min – PO at baseline; r=0.489, p =0.029, n=20). Further analysis of the results showed that 15 subjects (58%) obtained their highest PPO at the 8 min time point, while 7 subjects obtained their peak at 12 min, 3 subjects at 16 min and 1 subject producing his best result after only 4 min recovery in terms of upper body PPO. With regard to lower body PPO 14 subjects (70%) obtained their highest PO, PRFD and jump height at the 8 min time point, while 3 subjects obtained their peak at 12 min, the final 3 subjects produced their best results after only 4 min recovery. Therefore, the ability to harness PAP appears to rely on the strength levels of the subjects and the ability to harness the PAP effect and the optimal recovery time required to do so should be determined on an individual basis.

These findings may also provide an explanation for the ambiguity in the literature with regards to the existence of PAP with several studies that reported no change or a reduction in performance either using recovery periods of 5 minutes or less (Ebben, Jensen & Blackard 2000, Gossen & Sale 2000, Jensen & Ebben, 2003; Scott & Docherty 2004; Brandenberg, 2005; Robbins & Docherty 2005; Mangus et al., 2006; Hanson et al., 2007; Khamoui et al., 2009 and Matthews et al., 2009.) or subjects who were not resistance trained (Behm et al,. 2004; Gossen & Sale, 2000; Robbins & Docherty, 2005; Mangus *et al.* 2006 and Hanson et al., 2007). A recent study by Batista et al. (2010) attempted to examine the effect of strength training background on PAP response and reported that PAP was not affected by the strength training background, despite the significantly different levels of strength and power between groups. However, the protocol they employed utilised a standardised 4 minute recovery which may have been insufficient, particularly as individual analysis showed that 5 out of the 10-subject sample did increase their vertical jumps, which led them to suggest that that PAP may be subject dependent.

Whilst there is considerable support among the literature confirming the potential role of contractile history in enhancing subsequent contractions, there is no consensus with regard to the underlying mechanisms behind this (Hodgson, Docherty, & Robbins, 2005). To date, researchers have identified two potential mechanisms attributed to this increase in performance.

Firstly, PAP has primarily been attributed to the phosphorylation of myosin regulatory light chains (RLCs) (Sweeney, Bowman, & Stull, 1993; Grange, Vandenboom, & Houston, 1993), which is catalysed, by the enzyme myosin light chain kinase and dependent on the availability of calcium cations (Ca^{2+}). It is suggested that RLC phosphorylation causes a change in the tertiary structure of the myosin protein, which is facilitative to a faster rate of cross bridge cycling and force production (Sweeney, Bowman, & Stull, 1993; Grange, Vandenboom, & Houston, 1993).

Secondly, studies have commonly reported increases in H-reflex activity, which indicates an increased recruitment of higher threshold motor units, which would enhance force production, and importantly the RFD

(Gullich & Schmidtbleicher, 1996). Gullich and Schmidtbleicher (1996) have shown a strong relationship between the H-reflex and explosive isometric force development. However, Hodgson et al. (2008) and Shima et al. (2006) concluded that the enhancements observed as a consequence of PAP are associated with intrinsic physiological properties of the muscle and not electrical changes. Further research is certainly necessary to determine an accepted mechanism/s for PAP and it is recommended that future research attempts to look at the potential for the combination of these mechanisms, and whether the type of preload stimulus modulates this interaction in anyway.

The findings of Chapter 4 would also appear to provide further confirmation that stronger athletes are better able to utilise PAP. A view supported by Chiu et al. (2003) who reported athletically trained individuals to experience potentiation as a result of heavy back squats while performances of recreationally trained individuals were impaired. Chiu et al. (2003) cite greater muscle activation in the athletic trained population as allowing for greater H-reflex potentiation and/or RLC phosphorylation. In a similar vein Gourgoulis et al. (2003) demonstrated that athletes able to half squat in excess of 160kg exhibited a greater PAP response (4%) than athletes unable to (0.4%). Rixon, Lamont & Bemben (2007), although using a group of subjects with inferior strength levels to both Chiu et al. (2003) and Gourgoulis et al. (2003), were still also able to show a small effect of strength on PAP response, although not to significant levels. Ruben et al.

(2010) has reported higher correlations ($r = 0.81$, $P = 0.001$) between percentage PAP and 1RM performance. It may also be the case that stronger individuals have enhanced recovery mechanisms than weaker individuals and therefore require less recovery to be able to benefit from PAP. For example, Jo et al. (2010) demonstrated the recovery duration eliciting best performance in a Wingate cycle test to be significantly correlated with 1RM back squat ($r = -0.77$, $p < 0.05$).

The superiority of stronger athletes may also be explained through fibre type percentage. For example, given the role of type II muscle fibres in PAP response (Hamada et al., 2000; Hamada et al., 2003 and Tillin & Bishop 2009) fibre type distribution is certainly an important consideration. Given also that a strong relationship between strength and percentage of type II fibres has been well established (Aagard & Andersen 1998), it has been speculated that stronger subjects are able elicit greater benefits from PAP due to a greater percentage of type II muscle fibres (Vandervoort & McComas 1983).

Whilst further research is required to elucidate the exact mechanism involved, from a practical perspective, the strength levels of the athlete need to be taken into consideration when attempting to identify the most appropriate training strategy to employ.

The results of the Chapter 4 showed that average recovery period for the both the BBT and CMJ was 8 minutes. The results also demonstrated that subjects obtained their highest PPO at various intervals from 4 to 16 minutes, which suggests that the optimal recovery time needs to be determined on an individual basis in order to maximise the PAP effect. This was also confirmed by the findings of Chapter 5, which demonstrated that PAP can be harnessed to improve sprint performance providing adequate and individualised recovery is given between the pre-load stimulus and subsequent sprint activity. Having said that, the majority of the subjects in Chapter 5 performed their best sprint times 8 minutes post pre-load stimulus which is similar to the findings of Linder et al. (2010) who found improvements in 100m sprint times utilizing a 9 minute recovery period, whilst McBride, et al (2005), Rahimi (2007) Yetter and Moir (2008) reported improvements in 40m sprint times following 4 minutes recovery and Till & Cooke (2009) 4 – 6 minutes.

This evidence would suggest that PAP can be utilised to enhance performance in a sport related power activity such as sprinting with Linder et al. (2010) supporting the use of an 8 – 12 minute recovery period whilst also recognising that an individual response exists in terms of optimal recovery for PPO following a preload stimulus. These findings would suggest that further consideration of how best to apply these findings to a practical setting both in terms of training and as an ergogenic aid is merited. In addition, future research should include investigation of the effect of PAP on other power related sporting activities such as cycling, swimming, and in other power events where PAP may be utilised to enhance performance

PRACTICAL APPLICATIONS

- In order to develop PPO consideration needs to be given to the type of exercise employed and muscle group utilised, for example the optimal load for generating PPO was found to be on average 80% of 1 RM during the hang power clean (HPC), 30% of 1 RM during the Ballistic Bench Throw (BBT) and 0% of 1 RM in the Jump Squat (JS).
    - In addition, it is recommended that the optimal load should be determined on an individual basis.
- When using a HRT activity to potentiate subsequent performance the recovery period needs to be individualised however on average it was found to be 8 mins for both upper and lower body.
- Sprinting performance can be enhanced following 1 set of HRT providing adequate and individualised recovery is given between the pre-load stimulus and subsequent sprint activity.
- PAP appears to be affected by the strength of the individual, with stronger individuals demonstrating higher levels of potentiation.

FUTURE RESEARCH

The studies contained within this study highlight several issues that warrant further investigation. There is a need to elucidate the longer-term effects of training using various protocols including training at the optimal load, complex and contrast training. The mechanisms behind PAP and the relationship with maximal strength require further clarification, as does the potential use of a preload stimulus to potentiate performance related activities other than sprinting. Finally from a practical perspective the duration of the recovery period between the preload stimulus and the power activity may present a challenge and investigating the effects of performing resistance-training activities using different muscle groups during the recovery period or performing activities aimed at accelerating the recovery process would be valuable.

CHAPTER SEVEN

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APPENDICES

Experimental Data

Experiment 1

Squat Jumps

Name:	BM (kg)	3RM	Predicted 1RM (kg)	20%	30%	40%	50%	60%
1	118		194	4156	4305	3972	4053	3915
2	92		150	4608	4134	4063	3813	3823
3	94		174	3888	3761	3687	3714	3568
4	112		162	4281	4172	4077	3907	3707
5	83		168	3773	3840	3767	3692	3388
6	107		180	4375	4243	4288	4237	3655
7	107		180	4030	3877	3786	3635	3461
8	89.4		188	3719	3527	3527	3369	3395
9	102		175	3824	3698	3792	3681	3517
10	85		150	3570	3485	3315	3324	3218
11	113		176	5355	5212	4939	4668	4447
12	124	140	150	3985	4292	3931	3745	3709
13	114		198	4001	3973	3762	3712	3491
14	112	180	193	4722	4658	4451	4381	4098
15	78	150	160	3461	3461	3506	3346	3149
16	91		176	3899	3846	3751	3455	3329
17	96		187	3830	3968	3678	3577	3400
18	97		198	3964	3912	3868	3739	3701
19	97		203	4853	4577	4577	3973	3700
20	103		187	4256	4154	4173	4031	4119
21	115		242	4452	3918	3863	3938	3618
22	110		214	4346	3951	4016	3919	3628
23	99		187	4645	4539	4327	4177	4008
24	129	160	171	4826	4380	4140	4040	3839
25	90	140	150	3929	3550	3374	3342	3232
26	115	160	171	4870	4866	4819	4674	4375
27	99		175	5150	4699	4507	4827	4455
28	103	210	225	3887	3739	3672	3364	3382
29	118	170	182	4779	4315	4533	4355	4234
30	111	170	182	5200	5155	4817	4635	4560
31	119	200	214	4884	4767	4718	4574	4452
32	105	130	139	4103	4095	4016	4195	4106
33	109	150	160	4182	4140	3817	3939	3675
34	99	160	171	4317	4252	4156	3909	3909
35	80	150	160	3481	3222	3336	3189	3043
36	97	215	230	4864	4565	4300	4248	4244
Mean	103.1	###	181.2	4290.7	4145.8	4036.7	3927.1	3765.3
S.D	12.5	25.7	23.7	504.9	471.2	432.4	432.2	410.8

	BM (kg)		Peak Power (w)					
1	123.2	132	4215	3985	4292	3931	3745	3709
2	115.3	198	4214	4001	3973	3762	3712	3491
3	115.5	124	4773	4722	4658	4451	4381	4098
4	79.1	85	3994	3461	3461	3506	3346	3149
5	95.1	176	5509	3899	3846	3751	3455	3329
6	95.4	187	4970	3830	3968	3678	3577	3400
7	103	187	4807	4256	4154	4173	4031	4119
8	117.2	242	4879	4452	3918	3863	3938	3618
9	111.3	214	4773	4346	3951	4016	3919	3628
10	103.5	187	4832	4645	4539	4327	4177	4008
11	130.2	171	5034	4826	4380	4140	4040	3839
12	104	225	4012	3887	3739	3672	3364	3382
13	110.2	182	5292	5200	5155	4817	4635	4560
14	107.5	160	4730	4182	4140	3817	3939	3675
15	97.7	171	5798	4317	4252	4156	3909	3909
16	78	160	3962	3481	3222	3336	3189	3043
17	101.5	180	4971	4864	4565	4300	4248	4244

Bench Press Throws

Player	BM (kg)	3RM	Predicted 1RM (kg)	PP 20%	PP 30%	PP 40%	PP 50%	PP 60%
1	101	175	189	1278	1307.5	1134	1057	1011.5
2	95	116	125.28	669.5	844	773	696.5	592
3	82	96	103.68	510	559	513.5	476.5	416
4	118	126	136.08	888	909.5	828	740	753.5
5	112	115	124.2	525	957.5	964	924	864
6	110	115	124.2	786	806	833.5	680	599
7	107	120	129.6	902.5	861	838.5	794	767
8	89.4	110	118.8	673.5	670.5	608	576	560
9	92	101	109.08	736.5	726.5	652.5	612.5	608
10	85.5	140	151.2	929	850.5	822.5	753	650
11	131	160	172.8	1245	1218.5	1078	1074.5	886
12	91	106	114.48	681.5	728.5	657.5	625	579
13	107	121	130.68	1099.5	1083.5	1037.5	955.5	708.5
14	85.2	100	108	638.5	730	656	621.5	500.5
15	97	107.5	116.1	704.5	695.5	667	654.5	525
16	102	101	109.08	747.5	756.5	669.5	668.5	576
17	83	111	119.88	867	916.5	922.5	793	563.5
18	90		110	454	722	725	706	684
19	113		121	886	1007	1078	1008	1024
20	124		110	793	848	927	936	863
21	114		132	787	1177	979	1056	1003
22	112		104	624	742	824	772	689
23	104		110	788	1003	1037	1096	1028
24	86		110	667	751	800	811	830
25	78		93	574	600	641	613	598
26	91		110	661	709	751	822	719
27	96		110	512	808	825	850	828
28	97		126	726	852	873	808	787
29	97		140	977	1075	1111	1129	1039
30	103		115	666	814	847	799	714
31	115		132	719	915	854	847	790
32	85		137.5	769	813	817	831	807
33	110		143	740	1044	1057	1083	1022
34	99		115	710	842	877	812	769
35	115	105	112	776	876	946	894	832
36	99	105	112	695	755	711	723	625
37	103	115	123	765	861	905	871	840
38	118	100	107	616	701	672	692	664
39	111	140	150	947	1076	1009	964	954
40	119	130	139	947	1042	1033	939	885
41	105	105	112	755	774	889	923	816
42	108.7	125	134	960	1059	1070	1060	1004
43	99	140	150	860	999	1015	999	953
44	79.8	105	112	743	779	849	890	819
45	118	130	139	927	1028	1116	1029	979
46	97.2	137.5	147	946	1065	1042	1028	974
47	85	90	96	582	672	738	712	645
Mean	101.3		124	776	873	865	838	773
S.D	12.8		19	174	166	158	162	166

Hang Power Cleans

RDF

	30%	40%	50%	60%	70%	80%	90%
1		10231	11051	8322	15568	12520	16038
2	43453	41553	38863	50355	48891	64882	72435
3	16194.8	12937	18712	21718	21887	30949	29679
4	31946	34817	32435	30416	21475	29796	31811
5	19234	21232	20823	20968	18651	25950	23088
6	14118	13163	14478	12657	11537	13234	12324
7	32030	31052	23711	32026	30538	21122	21263
8			34534	35145	50352	47182	42605
9	16543	17324	18367	19267	15708	14366	16357
10	33557	32315	42833	52439	43924	47888	44123
11	45168	44185	44399	33642	16570	14296	16545
12	27744	28835	27906	24532	23225	26998	30954
Mean	27998.8	26149.5	27342.7	28457.3	26527.2	29098.6	29768.5
S.D	11237.2	11855.9	11213.7	13481.5	13709.7	16528.4	16952.8

Peak Velocity

	30%	40%	50%	60%	70%	80%	90%
1		1.76	2.10592	2.08168	1.84903	1.69795	1.82946
2	1.63594	1.75254	1.69692	1.71889	1.59288	1.56599	1.63318
3	1.82956	1.91682	1.96348	1.89687	1.812	1.7559	1.60969
4	1.86085	1.59543	1.876	1.70123	1.69246	1.55942	1.44855
5	1.65	1.67	1.77318	1.74616	1.55898	1.58308	1.55609
6	1.3337	1.41093	1.42761	1.45931	1.47991	1.43	1.41
7	1.31998	1.24794	1.51322	1.52318	1.77945	1.72377	1.55215
8			1.498	1.58606	1.82203	1.54338	1.4974
9	1.267	1.312	1.34948	1.35804	1.54557	1.49081	1.52082
10	1.86294	1.27455	1.41718	1.48346	1.44261	1.41492	1.232
11	1.63738	1.5599	1.61806	1.6961	1.69567	1.73084	1.623
12	1.38071	1.31429	1.46604	1.45162	1.4552	1.63203	1.54785
Mean	1.57781	1.52858	1.64209	1.64188	1.64382	1.59401	1.53835
S.D	0.23534	0.23019	0.24205	0.20761	0.15014	0.11611	0.14364

Peak Power (W)

	30%	40%	50%	60%	70%	80%	90%
1		5435.20	5614.58	5635.64	5393.83	5635.64	5566.62
2	3820.53	4483.77	4212.97	4619.35	4612.71	4631.70	5124.02
3	3655.79	4032.67	4332.99	4560.36	4603.71	4666.03	4077.84
4	3612.48	4206.63	4765.60	5306.95	5411.07	4970.8	4955.22
5	3645.00	3876.20	4359.68	4110.20	3732.59	3925.61	3949.51
6	2494.11	2966.89	2922.87	3122.37	3281.12	3454.30	3234.20
7	2159.99	2323.64	3117.43	3710.96	4150.13	4191.97	3859.18
8			3768.00	3926.34	5020.03	4339.15	4291.98
9	3423.00	3546.00	3685.70	3986.85	4873.08	4889.53	5185.52
10	3042.68	3029.40	3971.97	4442.80	4406.61	4465.68	4213.20
11	3562.78	3477.75	4013.41	4242.34	4416.37	4664.77	4324.20
12	3043.29	3004.44	3637.38	3934.68	3981.57	4809.45	4651.67
Mean	3245.96	3671.15	4033.55	4299.9	4490.23	4553.72	4452.76
S.D	552.811	863.301	719.173	683.063	642.609	551.163	664.082

Experiment 2

Lower Body

PPO

Subject ID	Baseline1	Basline 2	Baseline	0min	4min	8min	12min	16min	20min	24min
1	6501	6325	6413	5955	6462	6612	6512	6212	6215	6325
2	5353	5545	5449	5344	5425	5624	5510	5232	5398	5401
3	6326	6440	6383	5755	6311	6487	6394	6172	6214	6321
4	5069	5172	5120	4840	5106	5214	5268	4958	5001	5100
5	5348	5414	5381	5272	5347	5412	5425	5266	5314	5347
6	5296	5149	5223	4977	5131	5072	5245	4830	4788	4853
7	5948	5927	5938	5825	5910	6006	5898	5987	5862	5818
8	4929	4876	4903	4870	5121	4921	4741	4936	4905	4870
9	5703	6015	5859	5662	5917	6197	5430	5511	5185	5244
10	5218	5363	5291	5127	5523	5423	5116	5308	5157	5188
11	4749	4959	4854	4777	5816	5003	4760	4794	4752	4746
12	4586	4743	4664	4537	4676	4859	4674	4645	4684	4652
13	4854	4872	4863	4730	4924	5103	4610	4972	4872	4774
14	4862	4889	4875	4753	4949	5096	4968	4800	4878	4861
15	4545	4643	4594	4539	4530	4686	4541	4553	4351	4409
16	4472	4479	4475	4411	4458	4485	4395	4318	4329	4373
17	5642	5879	5760	5661	5612	5987	5396	5478	5501	5563
18	5191	5069	5130	5154	5024	5210	5087	5013	5114	5095
19	4784	4995	4889	4833	5127	5091	4869	5034	4973	5063
20	6920	6833	6877	6602	6781	6954	6912	6652	6592	6406
Mean	5314.733	5379.309	5347.021	5181.157	5407.481	5472.062	5287.582	5233.550	5204.356	5220.394
S.D	678.9492	654.581	663.3263	571.6184	635.7263	682.1377	686.371	610.187	610.9534	603.7881

Jump Height

Subject ID	Baseline1	Basline 2	Baseline	0min	4min	8min	12min	16min	20min	24min
1	0.347	0.347	0.347	0.326	0.338	0.351382	0.341247	0.302	0.325382	0.328
2	0.342	0.336	0.339	0.295	0.314561	0.340	0.33689	0.3321	0.3254	0.32415
3	0.342	0.353	0.348	0.322	0.383	0.365837	0.35	0.351	0.333168	0.353
4	0.318	0.31	0.314	0.29	0.314	0.33232	0.276	0.278	0.272204	0.265
5	0.274	0.299	0.287	0.248	0.277	0.286865	0.289	0.287	0.237478	0.275
6	0.301	0.323	0.312	0.291928	0.329	0.341	0.331	0.315	0.335866	0.321
7	0.338	0.338	0.338	0.355	0.355	0.356019	0.335	0.334	0.353398	0.338
8	0.289	0.293	0.291	0.266702	0.299	0.298	0.275	0.28	0.278685	0.275
9	0.322	0.33	0.326	0.312	0.3321	0.35434	0.316	0.3231	0.321	0.312
10	0.334	0.328	0.331	0.31	0.343	0.3568	0.344	0.325	0.333365	0.337
11	0.382	0.38	0.381	0.377	0.392303	0.401	0.383	0.38	0.38	0.373
12	0.231	0.246289	0.226564	0.21	0.236	0.244	0.23	0.232	0.239206	0.236214
13	0.388	0.3859	0.387	0.369	0.38816	0.408	0.385	0.37	0.37658	0.364808
14	0.280	0.27783	0.279	0.267	0.283187	0.294	0.292	0.289	0.283025	0.287171
15	0.423	0.428	0.425	0.404	0.41	0.4314	0.4214	0.412	0.387749	0.398815
16	0.372	0.3712	0.372	0.357	0.398	0.4124	0.3845	0.3814	0.37954	0.3871
17	0.429	0.431714	0.430	0.393	0.433	0.45214	0.45219	0.4217	0.4215	0.402
18	0.352	0.3564	0.354	0.346	0.358	0.371	0.343	0.344	0.336558	0.33
19	0.340	0.373	0.357	0.331	0.351701	0.371	0.358	0.349	0.361	0.351014
20	0.414	0.432	0.423	0.415	0.4214	0.43248	0.44214	0.378	0.398585	0.387
Mean	34.088	34.697	34.332	32.428	34.782	36.000	34.427	33.422	33.398	33.226
S.D										

PRFD

Subject ID	Baseline1	Basline 2	Baseline	0min	4min	8min	12min	16min	20min	24min
1	13206.6	16575.1	14890.8	14376.7	5298.1	17030.9	17616.4	16822.0	16908.0	16608.5
2	15534.8	13273.9	14404.4	12057.5	13137.5	16122.3	16700.0	15935.0	13619.7	15903.9
3	8255.4	9393.5	8824.5	6981.2	10314.0	14287.4	13019.7	7246.0	7618.7	9716.2
4	10116.0	10497.7	10306.9	6639.0	10866.0	13537.6	8169.5	7362.0	8970.5	9334.6
5	7888.1	9047.2	8467.6	5261.6	9440.0	13211.3	6590.4	6806.0	4674.2	5592.1
6	12149.0	12607.8	12378.4	18385.3	12902.0	18216.0	12810.4	18171.0	13132.7	10830.0
7	12007.0	12849.0	12428.0	10352.0	13462.0	13333.0	12356.4	12816.1	12193.9	14490.0
8	17224.8	17231.0	17227.9	19291.6	18259.0	20102.4	19577.0	18123.3	18023.4	22738.0
9	17598.0	16651.1	17124.6	12972.6	18183.4	22292.0	20753.0	16498.0	16205.0	11772.0
10	14869.0	14945.0	14907.0	14514.0	16911.1	18932.0	18866.0	16887.6	16471.2	17029.0
11	12445.5	11880.0	12162.8	13818.2	14855.0	16949.0	16242.0	15358.0	15076.0	14388.0
12	13852.5	14652.5	14252.5	14102.9	18719.0	15841.6	15529.4	16306.0	16497.0	15676.2
13	13972.5	13490.0	13731.3	9687.1	16024.6	20567.0	19096.0	14633.5	11696.7	12702.9
14	9679.2	9387.9	9533.6	9139.0	11224.0	13440.6	12690.8	9146.2	9324.5	12686.2
15	6742.5	7203.7	6973.1	5230.2	8419.0	8611.7	10159.4	8946.0	8711.1	7550.3
16	9734.0	6517.0	8125.5	9774.4	12507.2	14020.0	11653.7	10353.0	11154.3	12617.6
17	11791.1	11650.9	11721.0	10499.4	11565.0	14609.8	13104.7	11846.0	11927.2	14207.3
18	13176.3	13616.3	13396.3	14484.8	17645.6	23518.0	17753.5	16986.0	16876.9	19131.2
19	9187.6	11865.3	10526.4	10232.4	10019.5	13276.0	11712.6	10766.0	15235.3	8224.5
20	15218.4	16350.9	15784.6	13946.7	15230.0	17917.1	16570.3	12106.0	16078.0	16884.1
		Mean	12358.3	11587.3	13249.1	16290.8	14548.6	13155.7	13019.7	13404.1
		S.D	3011.8	3926.2	3697.5	3624.4	3911.8	3885.4	3717.6	4185.5

Upper Body

Peak Power Subject ID	Baseline	~15sec	4min	8min	12min	16min	20min	24min
1	912.8	707.2	870.4	933.6	956	910.4	867.2	884
2	948.8	847.2	938.4	984	1017.6	986.4	922.4	986.4
3	796.8	656.8	742.4	800	800.8	740	740.8	754.4
4	857.6	790.4	800	881.6	869.84	784.8	831.2	793.6
5	986.4	809.6	894.4	996.48	1012.32	921.6	892.8	829.6
6	1061.6	926.4	1088.8	1134.4	1091.2	1089.6	1109.6	1064.8
7	782.4	700.8	798.4	789.6	866.4	840	817.6	773.6
8	797.6	816.8	871.2	871.2	864.8	858.4	794.4	834.4
9	859.2	705.6	820.8	930.4	853.6	865.6	924	820
10	905.6	856.8	939.2	992	913.6	966.4	957.6	930.4
11	867.2	786.4	909.6	897.6	908	832	825.6	844
12	853.6	839.2	893.6	885.6	890.4	907.2	875.2	884.8
13	997.6	856.8	992.8	1012.8	981.6	1018.4	1003.2	983.2
14	698.4	612	707.2	742.4	695.2	721.6	724	708.8
15	1025.6	959.2	1103.2	1137.6	1071.2	1053.6	1045.6	1038.4
16	784.8	702.4	792.8	837.6	734.4	735.2	736	731.2
17	947.2	794.4	897.6	1039.2	952.8	827.2	919.2	957.6
18	888	815.2	844	886.4	805.6	872	846.4	884
19	853.6	777.6	884	859.2	872.8	878.4	855.2	811.2
20	921.6	821.6	904.8	985.6	951.2	904.8	914.4	947.2
21	683.2	656	683.2	734.4	691.2	608	656.8	573.6
22	1025.6	980	1061.6	1096.8	1048.8	1106.4	1004	1028.8
23	852.8	852.8	846.4	852	832	835.2	844.8	823.2
24	734.4	657.6	687.2	750.4	726.4	684.8	715.2	708
25	974.4	904.8	1012	974.4	996	948	936.8	917.6
26	845.6	750.4	873.6	884.8	878.4	851.2	872	847.2
Mean	879.3	791.7	879.1	918.8	895.5	874.9	870.5	860.0
S.D	100.4	96.7	112.6	113.0	111.7	121.4	106.8	115.8

Throw Height

Subject ID	**Baseline**	**~15sec**	**4min**	**8min**	**12min**	**16min**	**20min**	**24min**
1	0.311	0.261	0.337	0.325	0.357	0.348	0.333	0.334
2	0.354	0.327	0.383	0.395	0.417	0.467	0.405	0.423
3	0.323	0.31	0.33	0.36	0.36	0.36	0.329	0.344
4	0.293	0.249	0.268	0.3	0.29	0.25	0.257	0.244
5	0.32	0.299	0.338	0.35	0.364	0.351	0.375	0.32
6	0.56	0.45	0.55	0.588	0.521	0.54	0.548	0.528
7	0.281	0.215	0.27	0.289	0.326	0.3	0.293	0.244
8	0.34	0.33	0.334	0.35	0.35	0.285	0.295	0.35
9	0.376	0.32	0.35	0.386	0.361	0.348	0.345	0.342
10	0.327	0.314	0.32	0.349	0.332	0.343	0.322	0.329
11	0.364	0.326	0.343	0.38	0.346	0.306	0.298	0.345
12	0.378	0.34	0.368	0.371	0.379	0.354	0.376	0.37
13	0.427	0.405	0.467	0.454	0.448	0.47	0.472	0.432
14	0.211	0.16	0.177	0.207	0.199	0.189	0.19	0.194
15	0.467	0.415	0.48	0.482	0.484	0.437	0.46	0.455
16	0.299	0.284	0.318	0.346	0.321	0.333	0.3	0.337
17	0.399	0.326	0.382	0.41	0.404	0.342	0.355	0.367
18	0.372	0.345	0.354	0.393	0.39	0.388	0.36	0.362
19	0.379	0.367	0.38	0.393	0.403	0.384	0.418	0.4
20	0.315	0.288	0.331	0.364	0.335	0.344	0.338	0.33
21	0.31	0.29	0.31	0.337	0.303	0.289	0.29	0.272
22	0.4	0.388	0.423	0.432	0.438	0.416	0.426	0.4
23	0.32	0.3	0.329	0.306	0.32	0.32	0.327	0.306
24	0.28	0.267	0.257	0.274	0.277	0.244	0.285	0.282
25	0.409	0.35	0.431	0.42	0.393	0.356	0.376	0.351
26	0.366	0.277	0.367	0.387	0.367	0.389	0.367	0.388
Mean	35.3115	31.55	35.3731	37.1077	36.4808	35.2038	35.1538	34.8038
S.D	6.85381	6.184	7.55791	7.31508	6.66105	7.51439	7.42176	7.03372

Experiment 3

PAP & Sprinting

	Baseline	4 min	8 min	12 min	16 min	Baseline	4 min	8 min	12 min	16 min
1	1.83	1.85	1.84	1.85	1.83	1.04	1.09	1.06	1.07	1.06
2	1.92	1.90	1.86	1.91	1.93	1.17	1.12	1.11	1.13	1.13
3	1.91	1.90	1.89	1.89	1.89	1.13	1.13	1.11	1.11	1.11
4	1.88	1.88	1.89	1.90	1.90	1.13	1.09	1.09	1.12	1.11
5	1.80	1.82	1.80	1.80	1.87	1.06	1.03	1.02	1.05	1.07
6	1.77	1.71	1.78	1.72	1.72	1.06	1.02	1.06	1.02	1.02
7	1.74	1.78	1.67	1.68	1.74	1.01	1.02	0.99	0.99	0.98
8	2.00	1.94	1.93	1.94	1.94	1.16	1.15	1.14	1.14	1.16
9	1.83	1.89	1.85	1.86	1.88	1.08	1.12	1.10	1.10	1.11
10	1.86	1.87	1.95	1.81	1.78	1.03	1.20	1.24	1.07	1.04
11	1.90	1.83	1.85	1.84	1.78	1.08	1.10	1.11	1.09	1.05
12	1.76	1.77	1.78	1.77		1.02	1.05	1.02	1.06	
13	1.78	1.75	1.74	1.78	1.74	1.19	1.06	1.07	1.05	1.06
14	1.73	1.75	1.72	1.73	1.74	1.02	1.05	1.03	1.03	1.02
15	1.86	1.83	1.76	1.76	1.75	1.16	1.11	1.06	1.04	1.06
16	1.69	1.69	1.69	1.74	1.74	1.09	1.01	0.98	1.01	1.01
Mean	**1.83**	**1.82**	**1.81**	**1.81**	**1.82**	**1.09**	**1.08**	**1.07**	**1.07**	**1.07**
S.D	**0.08253**	**0.07398**	**0.08355**	**0.0765**	**0.079**	**0.05983**	**0.05354**	**0.06377**	**0.0445**	**0.04968**

ETHICS FORMS

Experiment 1

SPORT AND EXERCISE SCIENCE

SCHOOL OF HUMAN SCIENCES, SWANSEA UNIVERSITY
ETHICAL ADVISORY COMMITTEE

APPLICATION FOR ETHICAL COMMITTEE APPROVAL OF A RESEARCH PROJECT

In accordance with Departmental Safety Policy, all research undertaken in the department must be approved by the Departmental Ethics Advisory Committee **prior to** data collection. **Applications for approval should be typewritten on this form using the template available in the Public Folders.** The researcher(s) should complete the form in consultation with the project supervisor. Where appropriate, the application must include the following appendices:
(A) subject information sheet;
(B) subject consent form;
(C) subject health questionnaire.

After completing sections 1-12 of the form, 1 copy of the form should be handed-in to the Department Administrator who will then submit copies of the application for consideration by the Departmental Ethics Advisory Committee. The applicant(s) will be informed of the decision of the Committee in due course.

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1. DRAFT TITLE OF PROJECT

Optimal Loading for the Development of Peak Power Output in Professional Rugby Players

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2. NAMES AND STATUS OF RESEARCH TEAM

Mr Huw Bevan (PhD Student)
Dr. Liam Kilduff (PhD Supervisor)

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3. RATIONALE

The ability to develop high levels of muscular power is considered an essential component of success in many sporting activities. Consequently, researchers have examined the effectiveness of various training methods proposed to enhance power. As previously mentioned one training strategy consistently identified as a possible method for developing PPO requires athletes to train at the optimal load that maximises PPO (Harris et al, 2008; Mayhew et al., 1992; Mc Bride et al., 2002) however, to date there is no uniform agreement between researchers on the optimal load for peak power production with researchers suggesting that PPO can be produced when working against external loads that equate to 0% - 80% of 1RM. To date, there is a paucity of research examining the optimal load for PPO. Therefore in light of the above the aim of the proposed study is to determine the optimal load for PPO during the jump squat, bench throw and hang power clean in a group of professional rugby players.

4. REFERENCES

Harris, N. K., Cronin, J. B., Hopkins, W. G. & Hansen, K. T. Squat Jump Training at Maximal Power Loads Vs. Heavy Loads: Effect and Sprint Ability. *Journal of Strength and Conditioning Research*, 22: 1742–1749, 2008.

Mayhew, J. L., Johns, R. A. & Ware, J. S. Changes in Absolute Upper Body Power Following Resistance Training in College Males. *Journal of Applied Sports Science Research*, 6: 187, 1992.

Mcbride, J. M., Triplett-Mcbride, T., Davies, A., & Newton, R. U. The Effect of Heavy- Vs. Light-Load Jump Squats on The Development of Strength, Power, and Speed. *Journal of Strength and Conditioning Research*, 16: 75–82, 2002b.

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5. AIMS and OBJECTIVES

The aim of the current study was to determine the optimal load for peak power output during the jump squats, bench throw and hang power clean.

6. METHODOLOGY

Forty-seven professional male rugby players (mass mean 101.3, s = 12.8 kg; height mean 1.82, s = 0.08 m) will be recruited for this study. Players will perform BBP and SJ at loads of 20, 30, 40, 50 and 60% of their predetermined 1 RM in a randomised and balanced order. Power output (PO) will be determined using the Ballistic Measurement System (Fitness Technology, Australia). In addition12 professional rugby players will perform the hang power cleans on a portable force platform at loads of 30, 40, 50, 60, 70, 80 and 90% of the subject's predetermined 1 RM in a randomised and balanced order.

7. LOCATION OF THE PREMISES WHERE THE RESEARCH WILL BE CONDUCTED.

Ospreys Training Facility, Landore, Swansea.

8. SUBJECT RISKS AND DISCOMFORTS

Exercise has negligible risk in healthy adults, especially those well-trained, although there is a possibility that certain physiological changes may occur during the exercise tests. They include abnormal blood pressure, fainting and disorders of the heart. Subjects may suffer the effects of syncope immediately post exercise and are therefore asked to continue cool-down after testing in order to reduce the chance of this occurring.

A qualified first aider will be present at all testing sessions. This individual will be supported by the presence of other qualified staff (e.g. conditioning coach, physiotherapist) during some of the testing sessions.

9. INFORMATION SHEET AND INFORMED CONSENT

The submission should be specific about the type of consent that will be sought:

Have you included a Subject Information Sheet for the participants of the study ? YES

Have you included a Subject Consent Form for the participants of the study? YES

If written consent will not be obtained, explain why.

10. COMPUTERS

Are computers to be used to store data? YES

If so, is the data registered under the Data Protection Act? YES

NB : For UWS students, the answer to this question is YES, but the question has been included in order to stress the importance of adherence to the Data Protection Act in research activity

11. STUDENT DECLARATION

Please read the following declarations carefully and provide details below of any ways in which your project deviates from them. Having done this, each student listed in section 2 is required to sign where indicated.

1. I have ensured that there will be no active deception of participants.
2. I have ensured that no data will be personally identifiable.
3. I have ensured that no participant should suffer any undue physical or psychological discomfort
4. I certify that there will be no administration of potentially harmful drugs, medicines or foodstuffs.
5. I will obtain written permission from an appropriate authority before recruiting members of any outside institution as participants.
6. I certify that the participants will not experience any potentially unpleasant stimulation or deprivation.
7. I certify that any ethical considerations raised by this proposal have been discussed in detail with my supervisor.
8. I certify that the above statements are true with the following exception(s):

Student signature: (include a signature for each student in research team)

Date:

12. SUPERVISOR'S DECLARATION

In the supervisor's opinion, this project (delete those that do not apply):

- ~~Does not raise any significant issues~~.
- Raises some ethical issues, but I consider that appropriate steps and precautions have been taken and I have approved the proposal.

- ~~Raises ethical issues that need to be considered by the Departmental Ethics Committee.~~
- ~~Raises ethical issues such that it should not be allowed to proceed in its current form.~~

Supervisor's signature: Date:

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13. ETHICS COMMITTEE DECISION (COMMITTEE USE ONLY)

ETHICAL APPROVAL: GRANTED

The ethical issues raised by this project have been considered by members of the Departmental Ethical Approval Committee who made the following comments:

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....

Please ensure that you take account of these comments and prepare a revised submission that should be shown to your supervisor/ resubmitted to the Department Ethical Approval Committee (delete as appropriate).

Signed: Date:

(Chair, Departmental Ethics Advisory Committee)

SPORT AND EXERCISE SCIENCE
COLLEGE OF ENGINEERING, SWANSEA UNIVERSITY
ETHICAL ADVISORY COMMITTEE

SUBJECT CONSENT FORM

Contact Details: Huw Bevan (Ospreys Head Conditioner)

Project Title: Optimal Loading for the Development of Peak Power Output in Professional Rugby Players

Please initial box

1. I confirm that I have read and understood the information sheet dated ....../....../...... (version number ....) for the above study and have had the opportunity to ask questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. ☐

3. I understand that sections of any of data obtained may be looked at by responsible individuals from the University of Wales Swansea or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to these records. ☐

4. I agree to take part in the above study.

______________________	____________	______________________
Name of Subject	Date	Signature
Name of Person taking consent	Date	Signature
Researcher	Date	Signature

Experiments 2 & 3

SPORT AND EXERCISE SCIENCE

SCHOOL OF HUMAN SCIENCES, SWANSEA UNIVERSITY
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(D) subject information sheet;
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(F) subject health questionnaire.

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2. DRAFT TITLE OF PROJECT

Influence of Recovery time on Postactivation Potentiation in Professional Rugby Players

---

2. NAMES AND STATUS OF RESEARCH TEAM

Mr Huw Bevan (PhD Student)

Dr. Liam Kilduff (PhD Supervisor)

---

3. RATIONALE

The ability to develop high levels of muscular power is considered an essential component of many key activities performed in team sports (e.g. sprinting, change of direction). For example, Sleivert and Taingahue (2004) reported negative correlations between relative peak power output (PPO) during the split squat and 5 m sprint time (r=-0.65) and relative PPO during the traditional squat and 5-m sprint time (r=-0.66), which may indicate that increasing PPO will lead to an improvement in sprinting performance, a primary performance outcome in many team sports. Consequently, training methods aimed at improving an athletes PPO have received significant attention in the strength & conditioning literature recently. Recently, a training method that requires an athlete to work against a heavy load (e.g. pre-load stimulus, >80% 1 RM) followed by a light load (body mass) has been proposed to be an effective training method for enhancing power output in athletes. This method commonly refereed to as complex training is based on the physiological condition namely Postactivation Potentiation (PAP), with PAP defined as an acute enhancement of muscle function following a pre-load stimulus (Hodgson et al., 2005).

However currently there is conflict in the literature with regard to an athlete's ability to harness PAP while some of this conflict can in part be explained by numerous methodological differences in the various studies (e.g. intensity of preload used) (Hodgson *et al.*, 2005). While the majority of methodological limitations (e.g. preload intensity) can be overcome by careful study design, there is no uniform agreement about the optimal recovery time between the HRT and subsequent explosive activity with studies reporting recovery periods ranging from 0 to 18.5 min.

Therefore, due to the conflicting research in terms of appropriate recovery periods between the HRT and the subsequent explosive exercise, the aim of the present study was to determine the optimal recovery time for maximal benefits between the HRT (3 sets of 3 repetitions at 87% 1 RM) and the explosive activity in a group of professional rugby players.
In addition a secondly aim of this study was to determine the effect of PAP on 5 and 10 m sprint performance in professional rugby players.

4. REFERENCES

Sleivert G, Taingahue M. The relationship between maximal jump-squat power and sprint acceleration in athletes. *Eur J Appl Physiol.* 2004; 91:46-52.

Hodgson, M., Dochery, D. & Robbins, D. Post-Activation potentiation. *Sports Medicine, 2005;* 35: 585-595.

5. AIMS and OBJECTIVES

The aim of the current study was to determine effect of PAP on 5 and 10 m sprint performance in professional rugby players and to determine the influence of recovery of athletes ability to harness PAP.

6. METHODOLOGY

The aim of the present study was to determine the recovery time required to observe enhanced muscle performance following a bout of HRT. Twenty professional rugby players will be required to perform a countermovement jump (CMJ) and a ballistic bench throw at baseline and ~15 s, 4, 8, 12, 16, 20 and 24 min following a HRT bout (3 sets of 3 repetitions @ 87% 1RM of Squat). Power output (PO), jump height and peak rate of force development (PRFD) were determined for all countermovement jumps. In addition Sixteen professional male rugby players will be required to perform 5 10 m sprints (with 5 m split): baseline, 4, 8, 12 and 16 min after the preload stimulus (1 set of 3 repetitions at 91% 1RM).

7. LOCATION OF THE PREMISES WHERE THE RESEARCH WILL BE CONDUCTED.

Ospreys Training Facility, Landore, Swansea.

8. SUBJECT RISKS AND DISCOMFORTS

Exercise has negligible risk in healthy adults, especially those well-trained, although there is a possibility that certain physiological changes may occur during the exercise tests. They include abnormal blood pressure, fainting and disorders of the heart. Subjects may suffer the effects of syncope immediately post exercise and are therefore asked to continue cool-down after testing in order to reduce the chance of this occurring.

A qualified first aider will be present at all testing sessions. This individual will be supported by the presence of other qualified staff (e.g. conditioning coach, physiotherapist) during some of the testing sessions.

9. INFORMATION SHEET AND INFORMED CONSENT

The submission should be specific about the type of consent that will be sought:

Have you included a Subject Information Sheet for the participants of the study ? YES

Have you included a Subject Consent Form for the participants of the study? YES

If written consent will not be obtained, explain why.

10. COMPUTERS

Are computers to be used to store data? YES

If so, is the data registered under the Data Protection Act? YES

NB : For UWS students, the answer to this question is YES, but the question has been included in order to stress the importance of adherence to the Data Protection Act in research activity

11. STUDENT DECLARATION

Please read the following declarations carefully and provide details below of any ways in which your project deviates from them. Having done this, each student listed in section 2 is required to sign where indicated.

1. I have ensured that there will be no active deception of participants.
2. I have ensured that no data will be personally identifiable.
3. I have ensured that no participant should suffer any undue physical or psychological discomfort
4. I certify that there will be no administration of potentially harmful drugs, medicines or foodstuffs.
5. I will obtain written permission from an appropriate authority before recruiting members of any outside institution as participants.
6. I certify that the participants will not experience any potentially unpleasant stimulation or deprivation.
7. I certify that any ethical considerations raised by this proposal have been discussed in detail with my supervisor.
8. I certify that the above statements are true with the following exception(s):

Student signature: (include a signature for each student in research team)

Date:

12. SUPERVISOR'S DECLARATION

In the supervisor's opinion, this project (delete those that do not apply):

- ~~Does not raise any significant issues~~.
- Raises some ethical issues, but I consider that appropriate steps and precautions have been taken and I have approved the proposal.

~~Raises ethical issues that need to be considered by the Departmental Ethics Committee.~~

- ~~Raises ethical issues such that it should not be allowed to proceed in its current form.~~ ....
- ~~Raises ethical issues such that it should not be allowed to proceed in its current form.~~

Supervisor's signature: Date:

13. ETHICS COMMITTEE DECISION (COMMITTEE USE ONLY)

ETHICAL APPROVAL: GRANTED

The ethical issues raised by this project have been considered by members of the Departmental Ethical Approval Committee who made the following comments:

....

....

....

....

....

....

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....

Please ensure that you take account of these comments and prepare a revised submission that should be shown to your supervisor/ resubmitted to the Department Ethical Approval Committee (delete as appropriate).

Signed: Date:

(Chair, Departmental Ethics Advisory Committee)

SPORT AND EXERCISE SCIENCE
COLLEGE OF ENGINEERING, SWANSEA UNIVERSITY
ETHICAL ADVISORY COMMITTEE

SUBJECT CONSENT FORM

Contact Details: Huw Bevan (Ospreys Head Conditioner)

Project Title: Influence of Recovery time on Postactivation Potentiation in Professional Rugby Players

Please initial box

5. I confirm that I have read and understood the information sheet dated ....../....../...... (version number ....) for the above study and have had the opportunity to ask questions. ☐

6. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. ☐

7. I understand that sections of any of data obtained may be looked at by responsible individuals from the University of Wales Swansea or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to these records. ☐

8. I agree to take part in the above study.

______________________________ ________________ ________________________

Name of Subject Date Signature

______________________________ ________________ ________________________

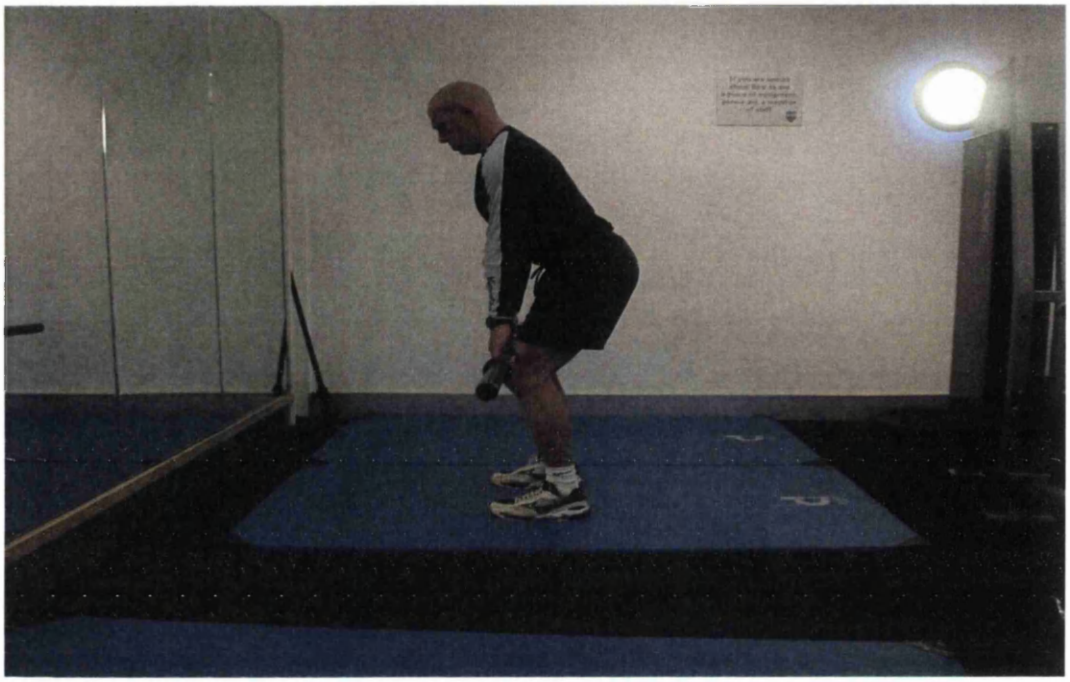
Name of Person taking consent Date Signature

______________________________ ________________ ________________________

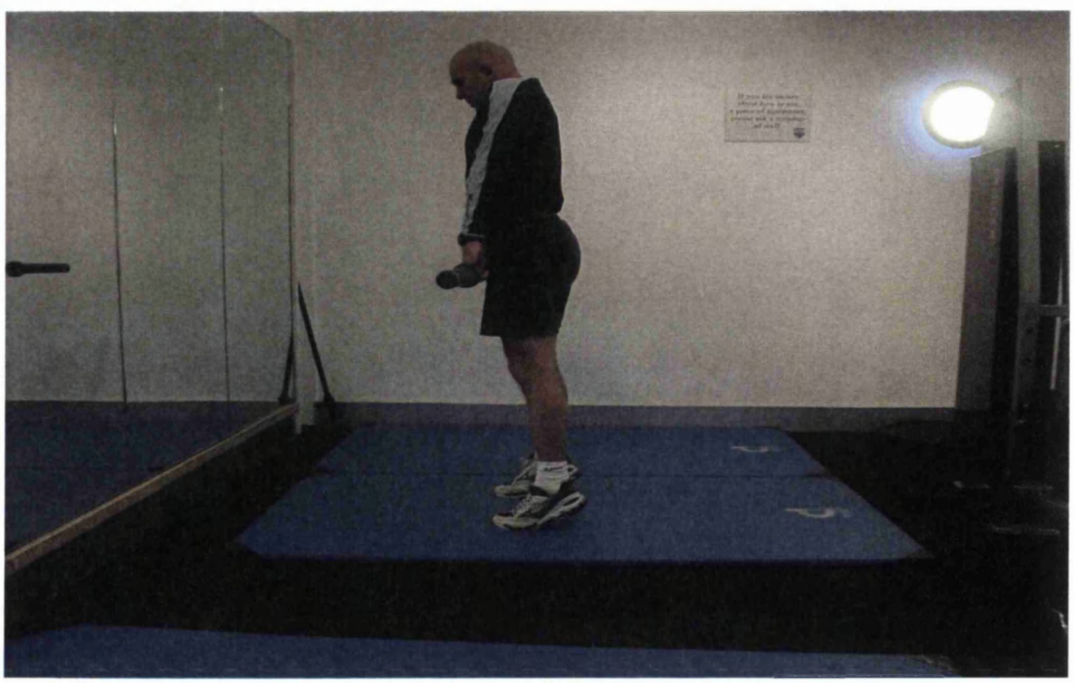
Researcher Date Signature

Photograph 1 Hang Power Clean

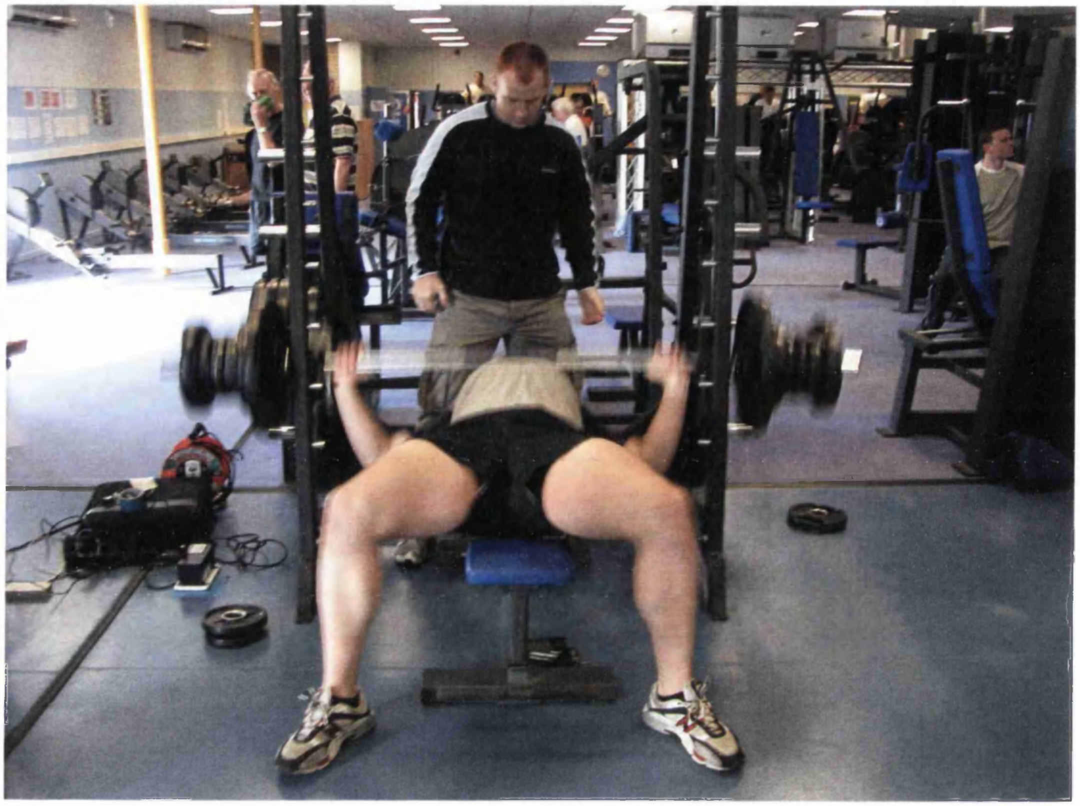
1.1 Start Position



1.2 Mid Point



Photograph 2. Bench Press Throw



Photopgraph 3 Jump Squat